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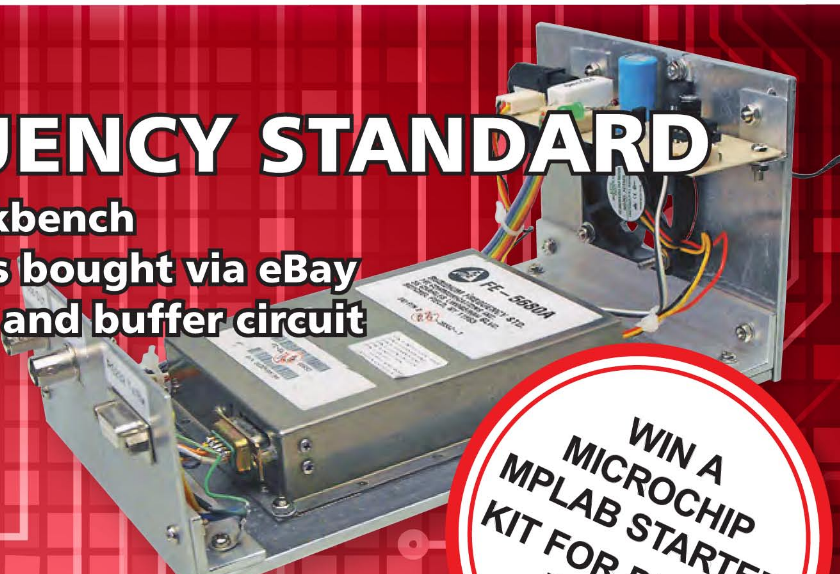

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USB/RS-232C Interface

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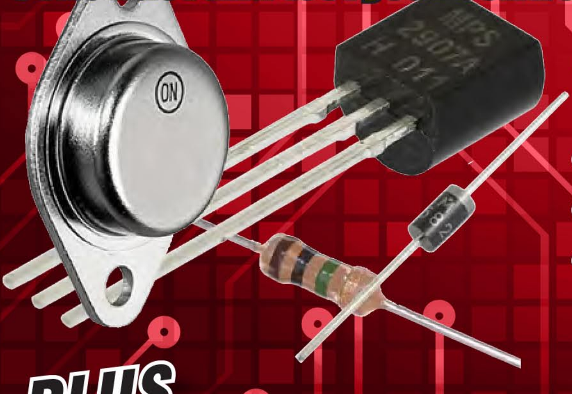
REVIEW OF A DIGITAL OUTPUT BOARD

10A/230V speed controller – PART 2

Construct and test your controller



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- Understand discrete linear circuit design
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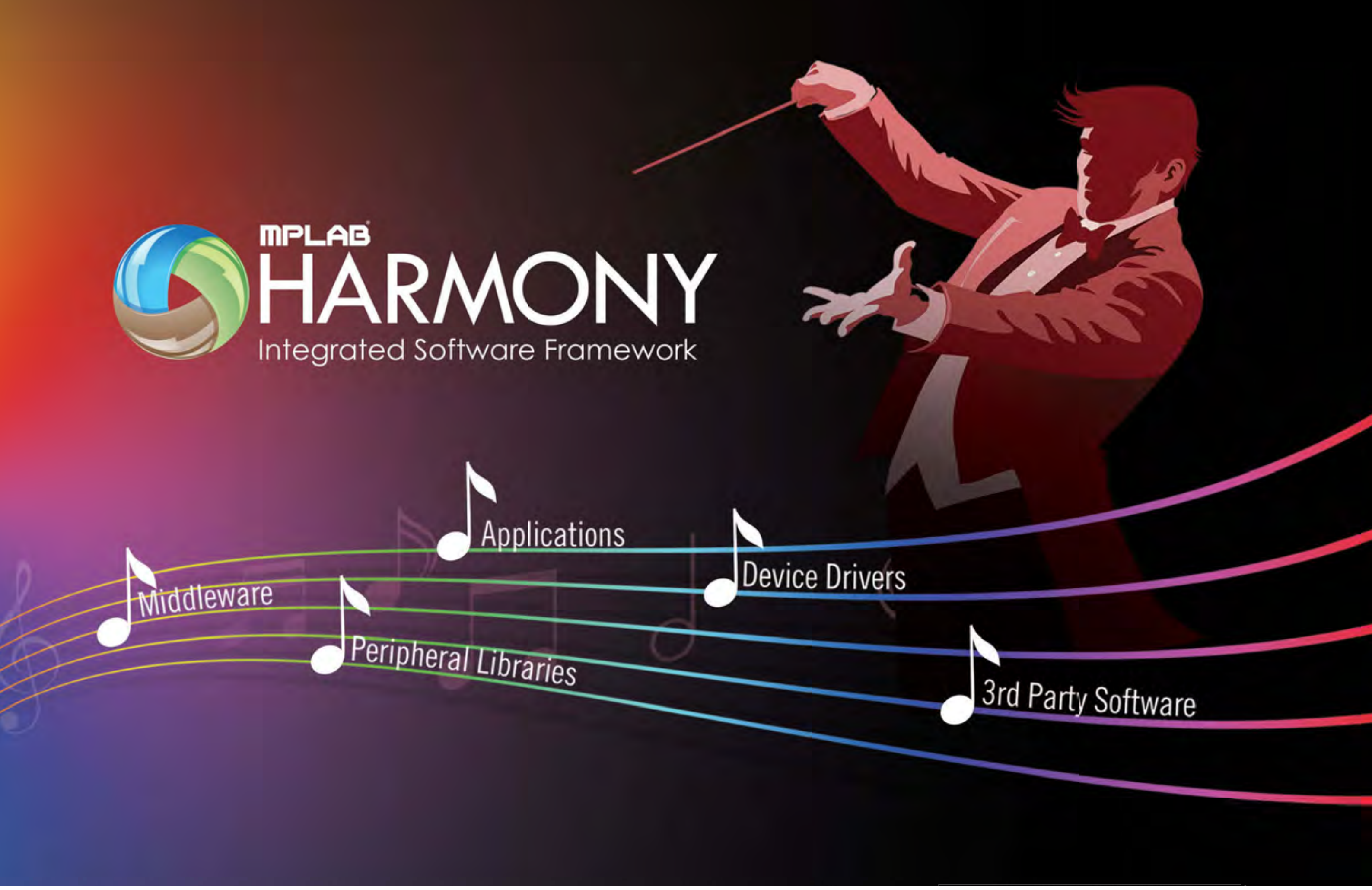

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- Modular achitecture allows drivers and libraries to work together with minimal effort

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- Integrated single platform enables shorter development time

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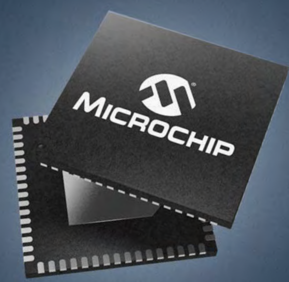

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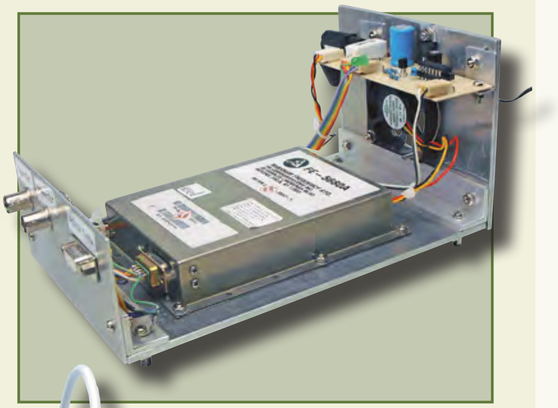

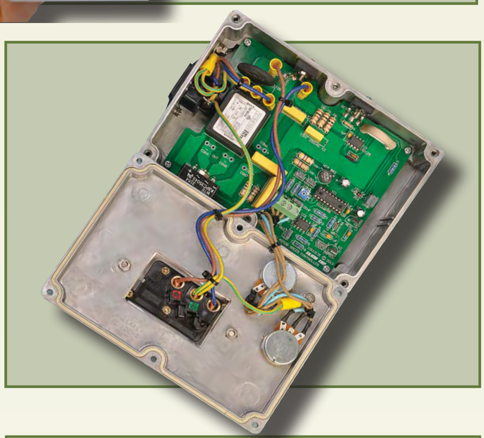

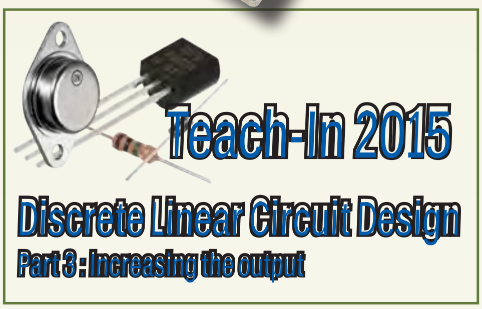

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USB & Serial Port PIC Programmer

USB or Serial connection. Header cable for ICSP. Free Windows software. See website for PICs supported. ZIF Socket & USB lead extra. 16-18Vdc.
Kit Order Code: 3149EKT - £49.95
Assembled Order Code: AS3149E - £64.95
Assembled with ZIF socket Order Code: AS3149EZIF - £74.95

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This tutorial project board is all you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. It programs all the devices a Microchip PICKIT2® can! You can use the free Microchip tools for the PICKit2™ and the MPLAB® IDE environment.
*Order Code: EDU10 - **£55.96***

ATMEL 89xxxx Programmer

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. 16Vdc.
*Kit Order Code: 3123KT - **£28.95***
*Assembled Order Code: AS3123 - **£39.95***

Introduction to PIC Programming

Go from complete beginner to burning a PIC and writing code in no time! Includes 49 page step-by-step PDF Tutorial Manual + Programming Hardware (with LED test section) + Windows Software (Program, Read, Verify & Erase) + a rewritable PIC16F84A. 4 detailed examples provided for you to learn from. PC parallel port. 12Vdc.
*Kit Order Code: 3081KT - **£16.95***
*Assembled Order Code: AS3081 - **£24.95***

PIC Programmer Board

Low cost PIC programmer board supporting a wide range of Microchip® PIC™ microcontrollers. Serial port. Free Windows software.
*Kit Order Code: K8076 - **£29.94***

PIC Programmer & Experimenter Board

PIC Programmer & Experimenter Board with test buttons and LED indicators to carry out educational experiments such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times. Software to compile and program your source code is included. Supply: 12-15Vdc.
*Kit Order Code: K8048 - **£23.94***
*Assembled Order Code: VM111 - **£39.12***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £11.52

USB Experiment Interface Board

5 digital input channels and 8 digital output channels plus two analogue inputs and two analogue outputs with 8 bit resolution.
*Kit Order Code: K8055N - **£25.19***
*Assembled Order Code: VM110N - **£40.20***

2-Channel High Current UHF RC Set

State-of-the-art high security. 2 channel. Momentary or latching relay output rated to switch up to 240Vac @ 10 Amps. Range up to 40m. Up to 15 Tx's can be learnt by one Rx (kit includes one Tx but more available separately). 3 indicator LEDs. Rx: PCB 88x60mm, supply 9-15Vdc.
*Kit Order Code: 8157KT - **£49.95***
*Assembled Order Code: AS8157 - **£54.95***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
*Kit Order Code: 3145KT - **£19.95***
*Assembled Order Code: AS3145 - **£26.95***
*Additional DS1820 Sensors - **£4.95 each***

Remote Control Via GSM Mobile Phone

Place next to a mobile phone (not included). Allows toggle or auto-timer control of 3A mains rated output relay from any location

Most items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix).

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, **Rings** to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ range. 112 x 122mm. Supply: 12Vdc/0.5A
*Kit Order Code: 3142KT - **£64.95***
*Assembled Order Code: AS3142 - **£74.95***

Audio DTMF Decoder and Display

Detect DTMF tones from tape recorders, receivers, two-way radios, etc using the built-in mic *or* direct from the phone line. Characters are displayed on a 16 character display as they are received and up to 32 numbers can be displayed by scrolling the display. All data written to the LCD is also sent to a serial output for connection to a computer. Supply: 9-12V DC (Order Code PSU375). Main PCB: 55x95mm.
*Kit Order Code: 3153KT - **£37.95***
*Assembled Order Code: AS3153 - **£49.95***

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone option and 2-wire serial interface for microcontroller or PC communication with simple command set. Suitable for common anode RGB LED strips, LEDs and incandescent bulbs. 56 x 39 x 20mm. 12A total max. Supply: 12Vdc.
Kit Order Code: 8191KT - £29.95
Assembled Order Code: AS8191 - £39.95

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

4-Channel Serial Port Temperature Monitor & Controller Relay Board

4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
*Kit Order Code: 3190KT - **£84.95***
*Assembled Order Code: AS3190 - **£99.95***

40 Second Message Recorder

Feature packed non-volatile 40 second multi-message sound recorder module using a high quality Winbond sound recorder IC. Standalone operation using just six onboard buttons or use onboard SPI interface. Record using built-in microphone or external line in. 8-24Vdc powered. Change a resistor for different recording duration/sound quality. Sampling frequency 4-12 kHz. (120 second version also available)
*Kit Order Code: 3188KT - **£29.95***
*Assembled Order Code: AS3188 - **£37.95***

Bipolar Stepper Motor Chopper Driver

Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
*Kit Order Code: 3187KT - **£39.95***
*Assembled Order Code: AS3187 - **£49.95***

Video Signal Cleaner

Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
*Kit Order Code: K8036 - **£24.70***
*Assembled Order Code: VM106 - **£36.53***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
*Kit Order Code: 3067KT - **£19.95***
*Assembled Order Code: AS3067 - **£27.95***

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
*Kit Order Code: 3166v2KT - **£23.95***
*Assembled Order Code: AS3166v2 - **£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£17.95***
*Assembled Order Code: AS3179 - **£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
*Kit Order Code: 3158KT - **£24.95***
*Assembled Order Code: AS3158 - **£34.95***

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
*Kit Order Code: 1074KT - **£15.95***
*Assembled Order Code: AS1074 - **£23.95***

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Designed by electronics enthusiasts for electronics enthusiasts! Powerful, compact and USB connectivity, this sums up the features of this oscilloscope.
40 MHz sampling rate, 12 MHz analog bandwith, 0.1 mV sensitivity, 5mV to 20V/div in 12 steps, 50ns to 1 hour/div time base in 34 steps, ultra fast full auto set up option, adjustable trigger level, X and Y position signal shift, DVM readout and more...
*Order Code: HPS50 - ~~£289.96~~ **£203.95***

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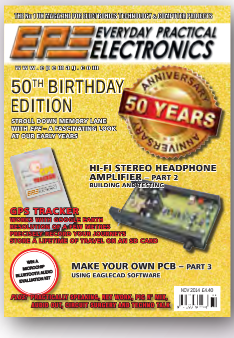

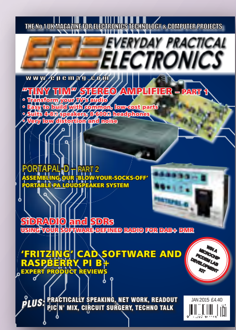

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PROJECTS • 2.5GHz 12-Digit Frequency Counter With Add-on GPS Accuracy – Part 1 • The Champion Amplifier • Simple 1.5A Switching Regulator •
FEATURES • Teach-In 2014 – Part 4 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • Net Work • PIC N' Mix • Net Work

FEB '14

PROJECTS • High-energy Electronic Ignition System – Part 1 • Mobile Phone Loud Ringer! • 2.5GHz 12-Digit Frequency Counter With Add-on GPS Accuracy – Part 2
FEATURES • Teach-In 2014 – Part 5 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • Net Work • PIC N' Mix • Net Work

MAR '14

PROJECTS • Infrasound Detector • Extremely Accurate GPS 1pps Timebase For A Frequency Counter • High-energy Electronic Ignition System – Part 2 • Automatic Points Controller For Your Model Railway Layout
FEATURES • Teach-In 2014 – Part 6 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • Net Work • PIC N' Mix • Net Work

APR '14

PROJECTS • Jacobs Ladder • Deluxe GPS 1pps Timebase For Frequency Counters • Capacitor Discharge Unit For Twin-Coil Points Motors
FEATURES • Teach-In 2014 – Part 7 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • Net Work • PIC N' Mix • Net Work • Beta-Layout's Re-Flow Oven Kit And Controller review

MAY '14

PROJECTS • Rugged Battery Charger • CLASSiC-D ±35V DC-DC Converter • Digital Multimeter Auto Power-Down • Control Relays Over The Internet With Arduino
FEATURES • Teach-In 2014 – Part 8 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • Net Work • PIC N' Mix • Net Work •

JUNE '14

PROJECTS • Cranial Electrical Stimulation Unit • Mini Audio Mixer • Adding Voltage And Current Meters To The Bits 'N' Pieces Battery Charger •
FEATURES • Teach-In 2014 – Part 9 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • PIC N' Mix • Net Work •

JULY '14

PROJECTS • Versatile 10-Channel Remote Control Receiver • Li'l Pulser Model Train Controller • Two Demonstration Circuits For Human Colour Vision •
FEATURES • Teach-In 2014 – Part 10 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • PIC N' Mix • Net Work • Audio Out •

AUG '14

PROJECTS • Active RF Detector Probe For DMMs • Add A UHF Link To A Universal Remote Control • PCBirdies • USB Port Voltage Checker • iPod Charger Adaptor •
FEATURES • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • PIC N' Mix • Net Work • Audio Out •

SEPT '14

PROJECTS • Build An AM Radio • LED Ladybird • Lifesaver For Lithium or SLA Batteries • 'Do Not Disturb!' Phone Timer •
FEATURES • Make Your Own PCBs – Part 1 • Techno Talk • Practically Speaking • Circuit Surgery • PIC N' Mix • Net Work • Audio Out • Max's Cool Beans •

OCT '14

PROJECTS • SiDRADIO: An Integrated SDR Using A DVB-T Dongle – Part 1 • Hi-Fi Stereo Headphone Amplifier – Part 1 • "Tiny Tim" Horn-Loaded Speaker System •
FEATURES • Make Your Own PCBs – Part 2 • Techno Talk • Interface • Circuit Surgery • PIC N' Mix • Net Work • Audio Out • Max's Cool Beans •

NOV '14

PROJECTS • GPS Tracker • Hi-Fi Stereo Headphone Amplifier – Part 2 • SiDRADIO: An Integrated SDR Using A DVB-T Dongle – Part 2 •
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DEC '14

PROJECTS • PortaPAL-D – Part 1 • Electronic Bellbird • SiDRADIO: An Integrated SDR Using A DVB-T Dongle – Part 3 •
FEATURES • 50 Golden Years of *Practical Electronics* – Part 2 • Techno Talk • Make Your Own PCBs – Part 4 • Interface • RPIADCISOL • Circuit Surgery • PIC N' Mix • Net Work •

JAN '15

PROJECTS • "Tiny Tim" Stereo Amplifier – Part 1 • PortaPAL-D – Part 2 • SiDRADIO – More reception modes •
FEATURES • Techno Talk • Teach-In 2014 Update Raspberry Pi B+ • Practically Speaking • Whizzkits Electronics Builder's Kit • Circuit Surgery • PIC N' Mix • Net Work • Audio Out • Max's Cool Beans • Fritzing Design Software

FEB '15

PROJECTS • "Tiny Tim" Stereo Amplifier – Part 2 • PortaPAL-D – Part 3 • Audio Delay For PA Systems •
FEATURES • Techno Talk • Teach-In 2015 – Part 1 • Interface • Circuit Surgery • PIC N' Mix • Net Work • Audio Out • Max's Cool Beans • RPI16IN

MAR '15

PROJECTS • Super Smooth, Full-Range, 10A/230V Speed Controller For Universal Motors • Stereo Echo & Reverb Unit • "Tiny Tim" Stereo Amplifier – Part 3 •
FEATURES • Techno Talk • Teach-In 2015 – Part 2 • Practically Speaking • Net Work • Circuit Surgery • PIC N' Mix • Audio Out • Max's Cool Beans •

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EVERYDAY PRACTICAL ELECTRONICS

Precision frequency standard

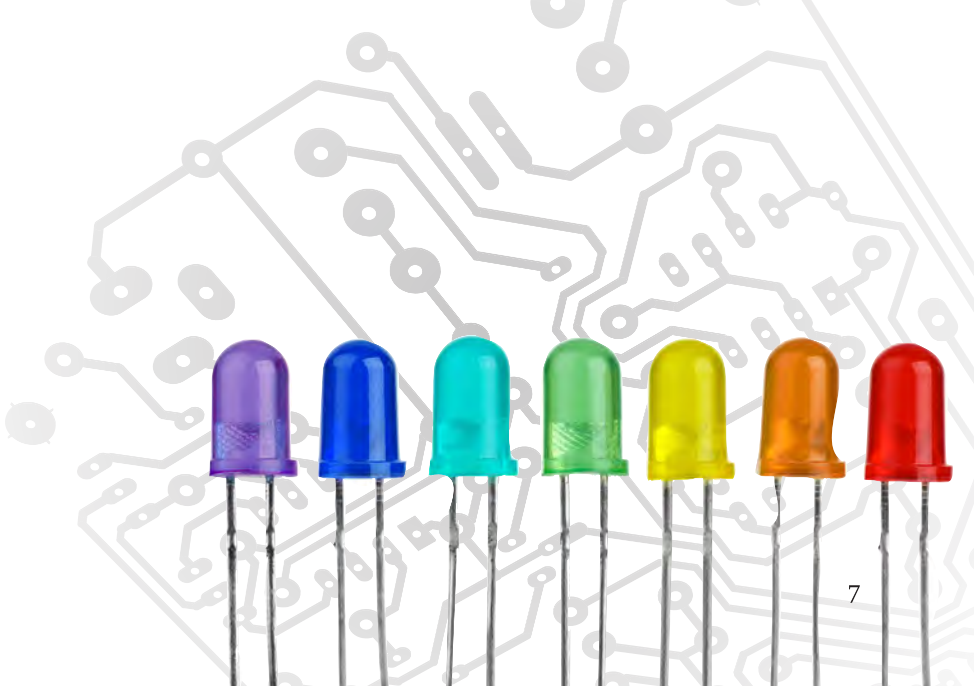
I want to highlight a couple of fascinating and very different projects for you this month. First is a real treat for all you precision electronics fans. We're offering you a chance to build a super-precise (if anything that is an understatement) frequency-measuring instrument using a second-hand rubidium standard. It did occur to me that we might be taking a bit of a risk with this project, since we cannot guarantee the supply of a second-hand component – you can of course buy new, but then the price shoots up painfully. However, checking eBay as we go to press I can see there is plenty of choice in terms of condition, price and location. So, even if you cannot find what you want straightaway, please be patient and I am sure the right device will present itself. This project is a lot of fun and I hope many of you enjoy constructing it.

Keeping RS-232C devices alive!

We all have them – perfectly good devices with a 9-pin D plug. But what do you do when faced with a modern computer that only recognises USB connectors? Well, it turns out that an RS-232C-to-USB convertor is a straightforward and satisfying project, so why not give your legacy accessories a new lease of life with our *USB/RS-232C interface*.

RIP Mr Laser

I must confess I had never heard of Charles Townes until I read a recent obituary of him. He died in January at the grand age of 99 and shared the 1964 Nobel prize for physics – won for his work developing practical microwave-emitting devices, called masers, and then the light-emitting version – the now-ubiquitous laser. These transformed electronics, communications, medicine, astronomy, warfare and even daily life in the home and at work. It is hard to imagine our world without lasers – from disk readers and barcode scanners to the light emitters that drive signals down Internet optical fibre – we would be stuck in a 1960s-style information slow lane without Charles Townes's laser.



NEWS

A roundup of the latest Everyday News from the world of electronics

Internet ignorance – report by Barry Fox

President Obama wants new laws to compel any hacked website to notify all subscribers within 30 days.

Hack notification

When Sony's PlayStation network was first hacked in 2011 and 77 million accounts were compromised, Sony notified subscribers and forced them to change their PS passwords. Other hacked sites have been less responsible.

Compulsion to notify will be worthless without better risk education. Many subscribers use the same password for several sites, to avoid a huge collection of different words to remember. So these other site passwords should also be changed.

Hacker strategy

The hackers may not immediately use the stolen data. They will store and sell it on. So it may be months or years before a user's other accounts are accessed, for instance to steal banking details or send spoof emails like: 'I am stranded and urgently need money', or to mount Denial of Service attacks where 'innocent' PCs are hijacked and used to shut down a corporate or government website by flooding it with traffic.

Educating users

There is also a shocking lack of education on the need to use anti-virus/malware protection on any device with semi-permanent storage, especially PCs with hard discs. Hackers can hold innocents to ransom by remotely infecting an unprotected PC (for instance through click links buried in emails) and then encrypting the hard disk until a fee is paid to unlock it.

PCs are now sold like toys, with no security software or software that needs enabling, updating and then paying for after a few months free trial. As I found out from some recent review tests, even the companies selling security software don't make it easy for PC owners to protect themselves.

Symantec *vs* Bit Defender

Symantec has led the market with Norton Internet Security, so I tried the rival Bit Defender. Making the change is a time-consuming one-way street because BD requires that all other protection must be removed, and this involves multiple re-boots. There is no going back.

Novice users are confronted with a bewildering choice between different purchase options – Bit Defender Antivirus Plus, Internet Security and Total Security – see: **www.bitdefender.co.uk**

I asked Bit Defender, why not give customers a simple proposition? What I got back in reply was just a detailed list of features.

I also told Bit Defender in detail about a technical problem; after a Bit Defender installation, Internet Explorer (Ver 11, with Windows 8) kept failing to find the home page (Google) and giving 'about:blank' error messages. The normal Internet options procedure for re-setting the home start page repeatedly failed. Bit Defender's web Support Centre, acknowledges the problem.

What I got back from Bit Defender on my problem report was a request for 'more details regarding the 'about: blank' message.'

Don't companies read their own websites?

There is an equally shocking lack of education on the need to back up the overall working state of a PC, and stored data. I have always recommended Acronis True Image for automating PC backups to a separate hard disc. But the Acronis website has for several years acknowledged the problem that the software can stop a PC shutting down for many hours, with the unhelpful message 'Operations are in progress, please wait. The machine will be turned off automatically after the operations are complete', see: **https://forum.acronis.com/forum/65516**

As I recently found out the hard way, forcing a shut-down – even after a day of waiting – can corrupt Windows and stop the PC re-starting.

Fortunately, I had an Acronis backup. Unfortunately, this proved to be useless because there was one bad backup in the middle of a long incremental chain.

Hard-won top tips

So here are three tips, regardless of what backup software you use.

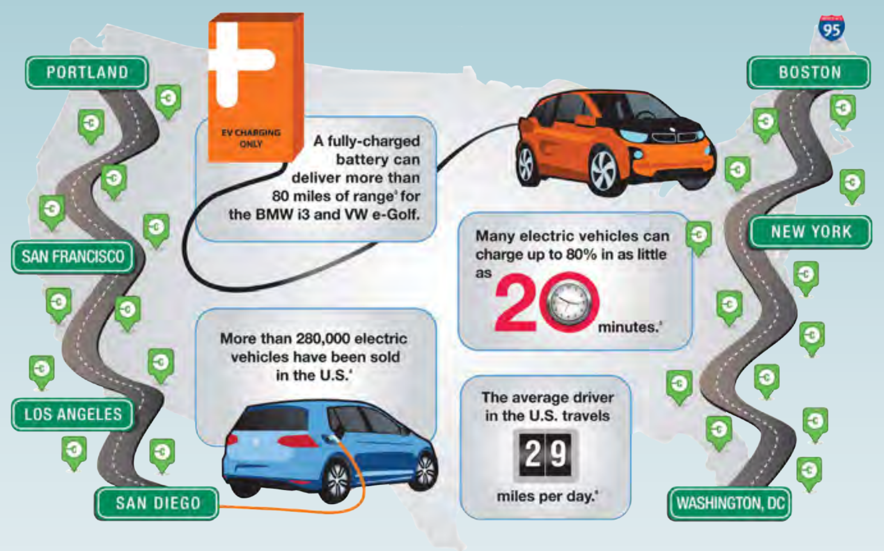
1. Do not rely on long chains of incrementals; force regular full backups.
2. Occasionally test them by deleting an expendable file and then trying to recover it from your latest backup.
3. Keep backups on separate drives and ideally at separate locations to guard against theft, fire or flood.

EPE EVERYDAY PRACTICAL ELECTRONICS

If you have some breaking news you would like to share with our readers, then please email:

editorial@wimborne.co.uk

Building US electric vehicle infrastructure



Two leading automakers, Volkswagen of America and BMW of North America, together with ChargePoint, the largest electric vehicle charging network, have announced an initiative to create express charging corridors along busy routes on the US East and West Coasts. Designed to increase the number of fast charging locations, the initiative will help meet the growing demand for publicly available electric vehicle fast chargers, including direct current (DC) Fast charging locations, and support the adoption of electric vehicles in the United States. In the initial phase, the aim is to install nearly 100 DC Fast chargers across both coasts, with plans to expand the program to increase access to fast charging across the country. These newly installed DC Fast chargers will be added to the growing ChargePoint network of more than 20,000 charging spots in North America.

Meeting demand

With more than 280,000 electric vehicles (EV) sold in the United States, EV owners need more charging flexibility while on the go. The express charging corridors will provide electric vehicle drivers access to DC Fast chargers along the most heavily populated and highly-trafficked regions on Interstate 95 on the east coast, from Boston to Washington DC, and on the west coast covering and connecting the metropolitan areas of Portland, San Francisco, Los Angeles, and San Diego. Installations will occur within and between relevant metro areas, strategically-spaced at a maximum of 50 miles apart.

Fast charge

Each fast charging location is expected to include up to two 50kW DC fast chargers, or 24kW DC combo fast chargers with the SAE Combo connector, used in both BMW and Volkswagen electric vehicles as well as many other electric vehicles that incorporate a DC Fast charging capability. When charging at a 50kW station, both the BMW i3 and the Volkswagen e-Golf can charge up to 80 per cent in 20 minutes. Both vehicles can also charge up to 80 percent in 30 minutes at a 24kW station.

Graphene supercaps

Oregon State University researchers have discovered a new way to absorb atmospheric carbon dioxide that's causing the greenhouse effect and use it to make an advanced, high-value material for use in energy storage products. This innovation in nanotechnology won't soak up enough carbon to solve global warming – but it will provide an environmentally friendly, low-cost way to make nanoporous graphene for use in 'supercapacitors'.

Supercapacitors are energy storage devices that can be recharged faster than a battery and have a great deal more power. Hence, they're used where rapid power storage and short, powerful energy release are needed.

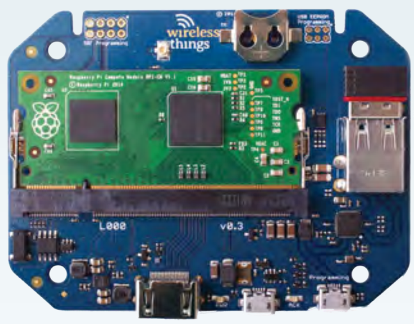
Using this new production technique the end result is a a pure form of carbon that's remarkably strong, can efficiently conduct heat and electricity and which has an enormous specific surface area of about 1,900 square meters per gram of material. Because of that, it has an electrical conductivity at least 10 times higher than the activated carbon now used to make commercial supercapacitors.

OpenPi launched on Kickstarter

Nottingham-based manufacturer 'wireless things' has announced the Kickstarter launch of its latest product 'OpenPi'.

OpenPi is a tiny wireless computer for innovators, makers and coders which has a Raspberry Pi Compute board at its heart. The wireless 32-bit ARM-based computer is a tool to help people who create software to prototype hardware, carry out customer trials and undertake small-scale manufacture. It is aimed at developers of wearable technology, the Internet of Things (IoT) and Smart Cities. Although it shares many similarities to the Pi, it also includes an on-board real-time clock and temperature sensor to give added functionality, and it is instantly usable thanks to a preloaded Linux operating system.

Further details are available at the wireless things website:
http://wirelessthings.net/openpi



Re-writable paper

According to some surveys, 90 percent of all information in businesses today is retained on paper, even though the bulk of this printed paper is discarded after just one-time use.

Such a waste of paper (and ink cartridges) not to mention the accompanying environmental problems such as deforestation and chemical pollution to air, water and land could be curtailed if the paper were 'rewritable' – capable of being written on and erased multiple times.

Chemists at University of California, Riverside have now fabricated a novel rewritable paper based on the colour switching property of commercial chemicals called redox dyes. The dye forms the imaging layer of the paper.

Printing is achieved by using ultraviolet light to photobleach the dye, except the portions that constitute the text on the paper. The new rewritable paper can be erased and written on more than 20 times without significant loss in contrast or resolution.

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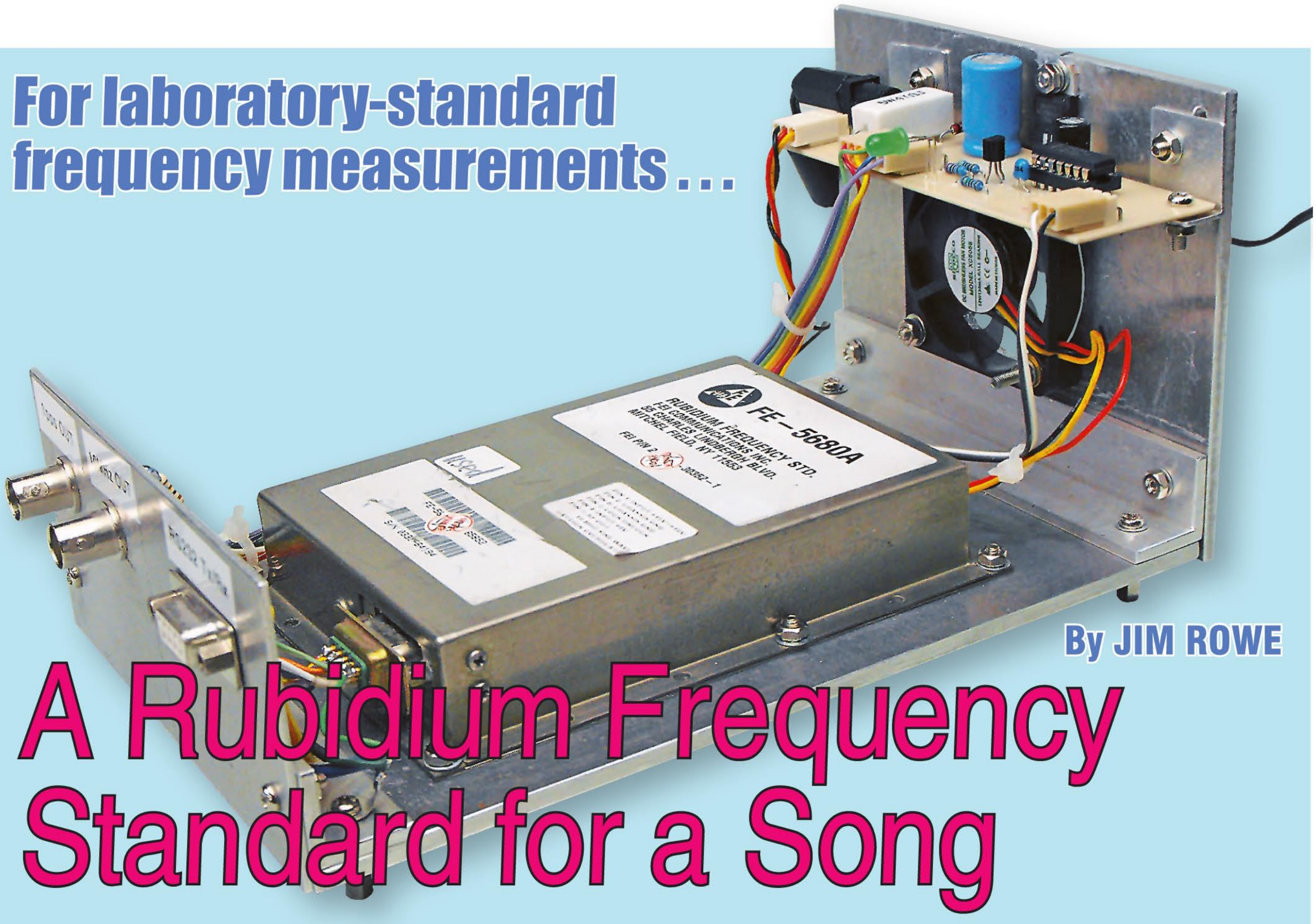


By JIM ROWE

A Rubidium Frequency Standard for a Song

How would you like to have a precision rubidium frequency standard on your workbench to enable you to make laboratory-standard frequency measurements? It's now possible, and for a very low price – just buy a used Rb-vapour frequency standard on-line and build a simple power supply and buffer circuit.

Used rubidium-vapour frequency standards are available via eBay from suppliers in China and elsewhere for very low prices. But how easy is it to get one of these devices going again? This article explains what was involved when I tried to get one up and running (it was really quite straightforward).

When researching this project-article, I discovered that quite a few ex-telecom Rb standards were being offered on eBay at very attractive prices – anywhere between $US99 and $US250 (plus shipping). So, I took the plunge and ordered one. It arrived a couple of weeks later and I began planning how to bring it back to life.

The unit I acquired was an FE-5680A (see photo), originally made by US firm Frequency Electronics Inc. This seems to be one of the most common 'retired' Rb-vapour standards currently on offer, although if you search on eBay and elsewhere you'll also find others like the LPRO-101 from Symmetricom/Datum/Ball/Efratom.

I should mention that although you'll find quite a few FE-5680A standards on offer, they're not all the same (even those that look almost identical). In fact, the model name 'FE-5680A' seems to have been used for a plethora of Rb-vapour frequency standards.

The many versions offer different options, such as: (1) the output frequency (10MHz, 2.048MHz, 5MHz, 10.23MHz, 13MHz, 15MHz or adjustable between 1Hz and 20MHz); (2) whether the RF output is a sinewave or a square wave; (3) whether or not the RF output is brought out via a separate SMA connector or simply via a pin on the unit's main DE-9 connector; and (4) whether or not it can be controlled remotely via a built-in RS232C serial interface.

Further options specify the required power supply voltage(s), whether or not it can be fine-tuned via an analogue tuning voltage (0-10V) and the polarity of the 'locked to rubidium' logic output signal (ie, LOCK or $\overline{\text{LOCK}}$).

So, you need to be cautious in selecting an FE-5680A from those being offered. If you intend using it as a frequency and time standard, choose one that's advertised as having a 10MHz sinewave output (available from either pin 7 on the DE-9 connector or from a separate SMA connector), can be controlled remotely via an RS-232C serial interface, has a $\overline{\text{LOCK}}$ output (on pin 3 of the DE-9 connector) and needs both +15-18V and +5V supplies (this is the version I bought).

Step 1: collecting info

Although the FE-5680A I bought had a small label on the top of the case showing the main DE-9 pin connections and the supply voltages, it didn't identify all the pins and their functions. So before attempting to fire it up, I decided to collect as much information on the FE-5680A series as I could.

A quick search on the Internet soon turned up quite a lot of useful information. Most of this came from the links shown in the 'Handy Links' panel at the end of this article – so I suggest you go to these first to save time. The Time Nuts mailing list archive is particularly informative, not just regarding the FE-5680A, but for all kinds of stuff on time and frequency standards and their use.

Most of the important information on the FE-5680A is summarised in Fig.1. Armed with this data, I was then able to knock up a suitable power supply on a breadboard. This comprised a surplus 18V/2.5A laptop PC power supply to provide the main 15-18V rail, plus a simple 3-terminal regulator to derive a +5V logic supply rail.

At that stage, I was simply going to power up the FE-5680A, so I didn't provide anything else as I thought I'd be able to do all of the initial checking with a digital multimeter, digital scope and a frequency counter.

Step 2: applying power

When you first apply power to a rubidium-vapour standard like the FE-5680A, it draws a fairly substantial current from the main 18V supply (about 1.8A). That's because it has to 'warm up' everything inside the 'physics package'. It's only after the electronic circuitry has been able to achieve frequency lock (to the frequency corresponding to the energy difference between the two 'hyperfine split ground state' levels of the rubidium atoms in the resonance cell) that the current begins dropping down to its 'running locked' level of 600-900mA. This usually takes no more than about five minutes.

During this time, the current drain stays relatively high until locking is achieved, and if you monitor the RF output (at pin 7 on the DE-9M connector) with a counter, you'll find that it swings up above 10MHz and then swings down below this again. Generally, it repeats this up-and-down sweeping a number of times, as the electronics 'searches' for the small dip in the photodetector's output, which corresponds to rubidium resonance. Then, when the dip is found, the output frequency is 'locked to rubidium' – ie, very close to 10.000000MHz.

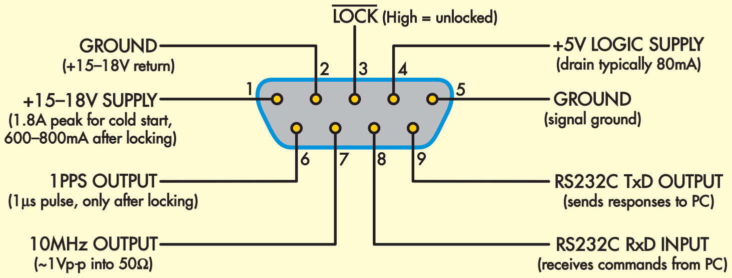
The internal logic also pulls down the voltage level of the $\overline{\text{LOCK}}$ output (pin 3 of the DE-9M connector), while a 1µs-wide output pulse appears at the 1pps output (pin 6) once every second. But neither of these happens unless a lock has been achieved.

When I first applied power to my FE-5680A, I was monitoring the current drawn by pin 1 of the DE-9M connector with one DMM and the voltage at pin 3 with another DMM. Sure enough, the current drain started off at about 1.85A and then began dropping – slowly at first and then somewhat more rapidly until it nudged below 800mA. This took about seven minutes, but as the unit probably hadn't been powered up for a few months I wasn't unduly concerned about the time it had taken.

What did concern me though, was that the voltage monitored at pin 3 ($\overline{\text{LOCK}}$) remained high at about +4.9V,

FE-5680A Series Rubidium Frequency Standard – Basic Information

DE-9M Connector Pinouts (as viewed from front):



Basic Specification:

Output Frequency:	10MHz
Waveform:	sinusoidal
Minimum amplitude:	0.5V RMS into 50Ω
Adjustment Resolution:	$<1 \times 10^{-12}$ over range of 3.8×10^{-5}
Short Term Stability:	1.4×10^{-11} (1 – 100 seconds)
Drift:	2×10^{-9} per year, 2×10^{-11} per day
Phase Noise:	–100dBc @ 10Hz; –125dBc @ 100Hz; –145dBc @ 1000Hz
Input Voltage Sensitivity:	2×10^{-11} (15V – 16V)
Frequency vs Temp:	$\pm 3 \times 10^{-10}$ (–5°C – 50°C)
Spurious Outputs:	–60dBc
Harmonics:	–30dBc
Warm-up Time:	<5 minutes to lock, at 25°C

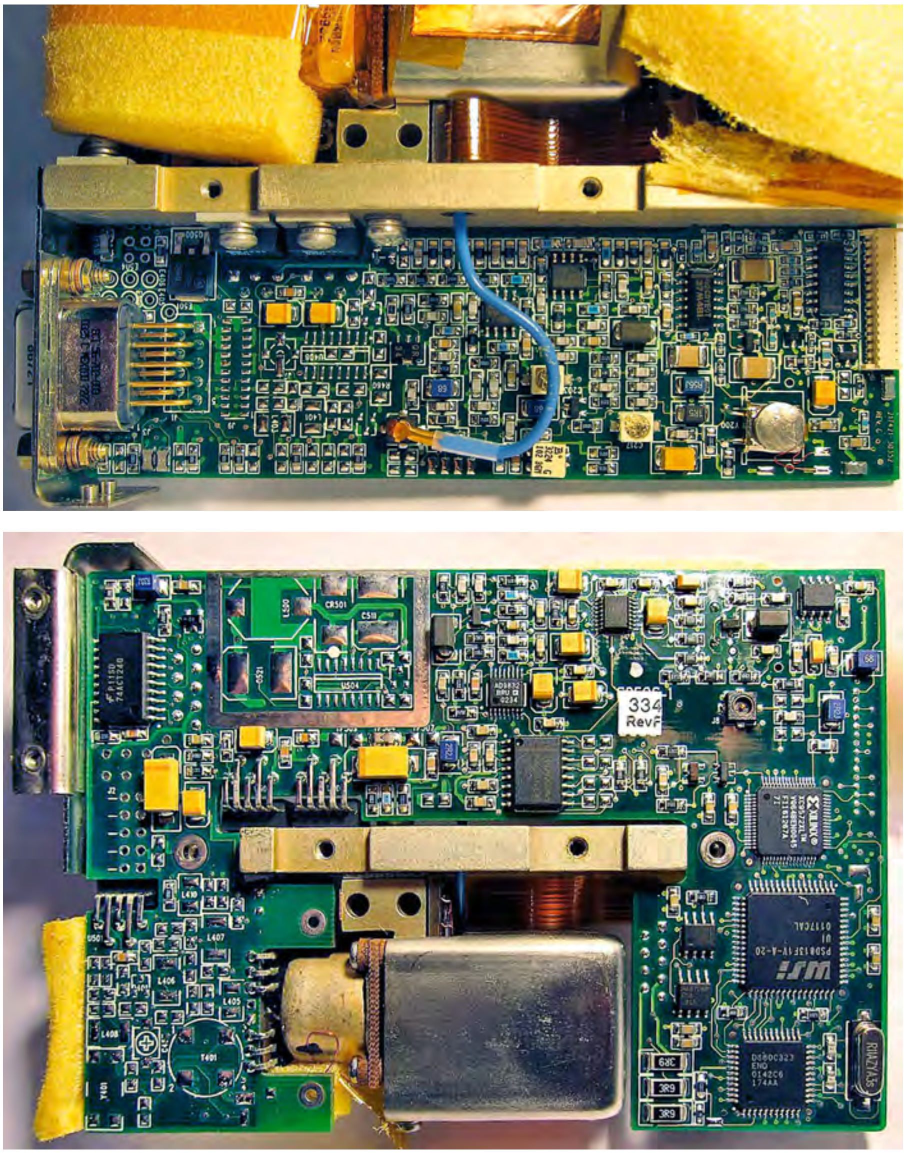
RS232C Serial Commands & Responses from the FE-5680A (9600 bps, 8N1, no handshaking)

COMMAND FORMAT (hex)	FUNCTION	RESPONSE BY FE-5680A
2D 04 00 29	Request current Frequency Offset	2D 09 00 24 aa bb cc dd <dcsm>*
2E 09 00 27 aa bb cc dd <dcsm>*	Change temporarily to a new Frequency Offset	(Temporarily changes Frequency Offset to [aa bb cc dd] hex)
2C 09 00 25 aa bb cc dd <dcsm>*	Change Frequency Offset to new value, Save in EEPROM	(Changes Frequency Offset to [aa bb cc dd] hex, saves in memory)

* <dcsm> = Ex-OR (bitwise) checksum of all four preceeding hex data bytes [aa, bb, cc, dd]

Fig.1: here are the pin connections, the main specifications and the RS232C commands for the FE-5680A series of rubidium frequency standards.

Used FE-5680A Rb-vapour standards are available on eBay from China for less than £100 including postage.



These photos show the 'works' inside an FE-5680A rubidium standard with its mu-metal case removed. The upper shot is a top view, with the physics package and its shock-protective foam at the top. The quartz oscillator crystal is at lower right, with a silver-coloured thermistor above it. To its left is the small trimcap (C217), used to correct for long-term drift. The lower shot shows the underside of the assembly, with the underside of the physics package at bottom centre.

showing that the FE-5680A still hadn't locked. There were no 1pps pulses appearing at pin 6 either – another sign that it hadn't locked.

The 'clincher' came when I started to monitor the FE-5680A's RF output (pin 7) with my counter. It was still sweeping up and down between about 9,999,790Hz and 10,000,065Hz, every 10-15 seconds or so. Clearly it was going through the motions of searching for a lock, but for some reason never finding it.

I left it searching this way for an hour or so, in case it was especially slow on the uptake. However, when it still hadn't achieved a lock after two hours, I turned off the power and went back to the Time Nuts archive and KO4BB's FAQs, looking for clues on how to tackle an FE-5680A that wouldn't lock.

One clue I found was that if an FE-5680A wouldn't lock, it could be because the internal crystal oscillator had 'drifted' a bit in frequency. This could be enough to prevent the 'searching for a lock' sweeping operation from swinging sufficiently either side of the lock frequency (ie, above and below 10MHz). The solution was to open the unit up and adjust a small trimmer capacitor near the crystal (C217), to correct for the drift.

However, I was dubious as to whether this was the cause of my particular unit's problem, because it did seem to be sweeping above and below 10MHz by a comfortable margin. So I signed up to the Time Nuts mailing list/forum and posted a request for any further information that might be forthcoming from the experts.

There were a few further suggestions, but when I tried these out my unit still refused to lock. As a result, I removed the two halves of the FE-5680A's mu-metal case to reveal its 'works'. It was then just a matter of finding trimmer C217, giving it a small nudge (clockwise at first, because there was no hint as to which would be the correct direction), then screwing on the two case halves again and testing to see whether it would now lock.

It still wouldn't lock, and when I subsequently used a counter to check the maximum and minimum frequencies while it was searching, these didn't seem to be all that different. So perhaps I had picked the wrong direction for my initial nudge of C217? There was nothing for it but to open it up again and try giving C217 a slightly larger nudge, this time in an anticlockwise direction.

It still refused to lock so I repeated this process a few more times but still without success. Then, deciding that the problem must be due to something else, like a worn-out rubidium lamp or a broken photodetector, I began looking around inside the unit and checked a few voltages and signal frequencies.

By this stage I had discovered a partial schematic for the FE-5680A, which can be downloaded from the last link in the Handy Links panel. However, this didn't turn out to be very helpful when it came to this particular problem, because it doesn't include any details of what's inside the 'physics package' – like the lamp or photodetector.

I was getting nowhere, so I contacted the eBay vendor I'd bought it from and he offered to replace the unit. I duly sent it back and the replacement unit turned up a few weeks later.

When it was unpacked, it appeared to be identical to the first unit, apart from having a different serial number. I connected it up as before, monitoring the current from the +18V supply and the voltage at the $\overline{\text{LOCK}}$ pin using two DMMs. As before, I also used my counter to monitor the output frequency as it searched for a lock after switch-on.

What happened then was exactly the same as with the first unit. The scope showed that there were no pulses from the 1pps output and the counter showed that the RF output was just sweeping back and forth through 10MHz, without showing any signs of a lock. This continued despite leaving it on for another hour or so.

By the way, I had previously read that rubidium standards like the FE-5680A should not be allowed to run for very long without using a cooling fan, so I had pulled a small 12V fan from the junk box and rigged it up to keep the unit from getting too hot.

A lucky breakthrough

I went back to scouring the various reference sources, to see if I could find the answer. And after a while I found a note that the physics package in rubidium standards was quite sensitive to external magnetic fields – that's the reason for housing them inside a mu-metal enclosure, after all. I then wondered if the difference between the Earth's magnetic field in Sydney and Quangzhou might be just enough to result in a 'failure to lock' – despite the mu-metal enclosure or perhaps because the enclosure had somehow become magnetised.

It occurred to me that one way to test this theory might be to turn the 'new' FE-5680A upside down, to roughly reverse the direction of the Earth's field around it. So I turned it off, let it cool down, turned it upside down and then turned the power on again.

Bingo! Within about three minutes, it found a lock and stayed locked for another few hours while I left it on to make sure. The voltage at the $\overline{\text{LOCK}}$ output (pin 3) stayed down at about +0.35V, while the scope showed 1µs-wide 1pps pulses coming from pin 6. What's more, the counter remained steady at a reading very close to 10MHz, even when I changed to longer and longer gating times to achieve maximum resolution.

Only when I went to a 1000-second gating time did I see that the FE-5680A's output frequency was a whisker below 10MHz: 9,999,999.992Hz, in fact.

At that stage, I hadn't made any attempt to adjust the 'offset' by sending commands to it from a PC via the RS232C serial port. So the unit was still running with whatever offset figure had been stored in its EPROM way-back-when. Small wonder that it was locking to a frequency of 'not-quite' 10MHz but just 0.008Hz (eight milliHertz!) short of it.

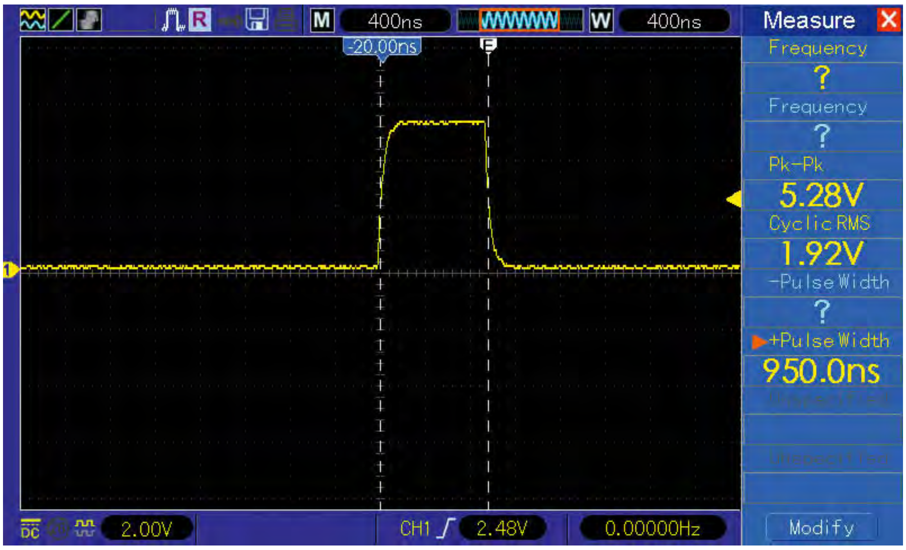


Fig.4: once the FE-5680A has 'locked to rubidium', it provides one of these 950ns-wide 1pps output pulses each second.

By the way, the exact resonant frequency of the resonance cavity inside every rubidium-vapour reference depends on many parameters, some of them quite subtle. That's why they need to be programmable in terms of the 'offset' that needs to be applied to their internal frequency synthesiser, to bring their locked output frequency to the correct figure. This offset programmability also allows them to be recalibrated from time to time, to correct for any long-term drift.

It even allows them to be 'locked' to the GPS system, by comparing the timing of their 1pps pulses with those from a GPS receiver, but more about this later.

Another surprise

So why did the FE-5680A have to be turned upside down to achieve the lock? I could only guess that it was because of the slightly different flux density and orientation of the Earth's magnetic field at my house.

To check this theory, I turned the power off and let it cool down again. I then returned it to the right-side-up orientation and reapplied power. Much to my surprise, it quickly achieved a lock, this time in about two minutes and 25 seconds. And when I repeated this test a few more times, the same thing happened!

Somehow, whatever had initially prevented it from achieving a lock when it was the right way up had fixed itself and the unit was now able to lock reliably, regardless of its orientation.

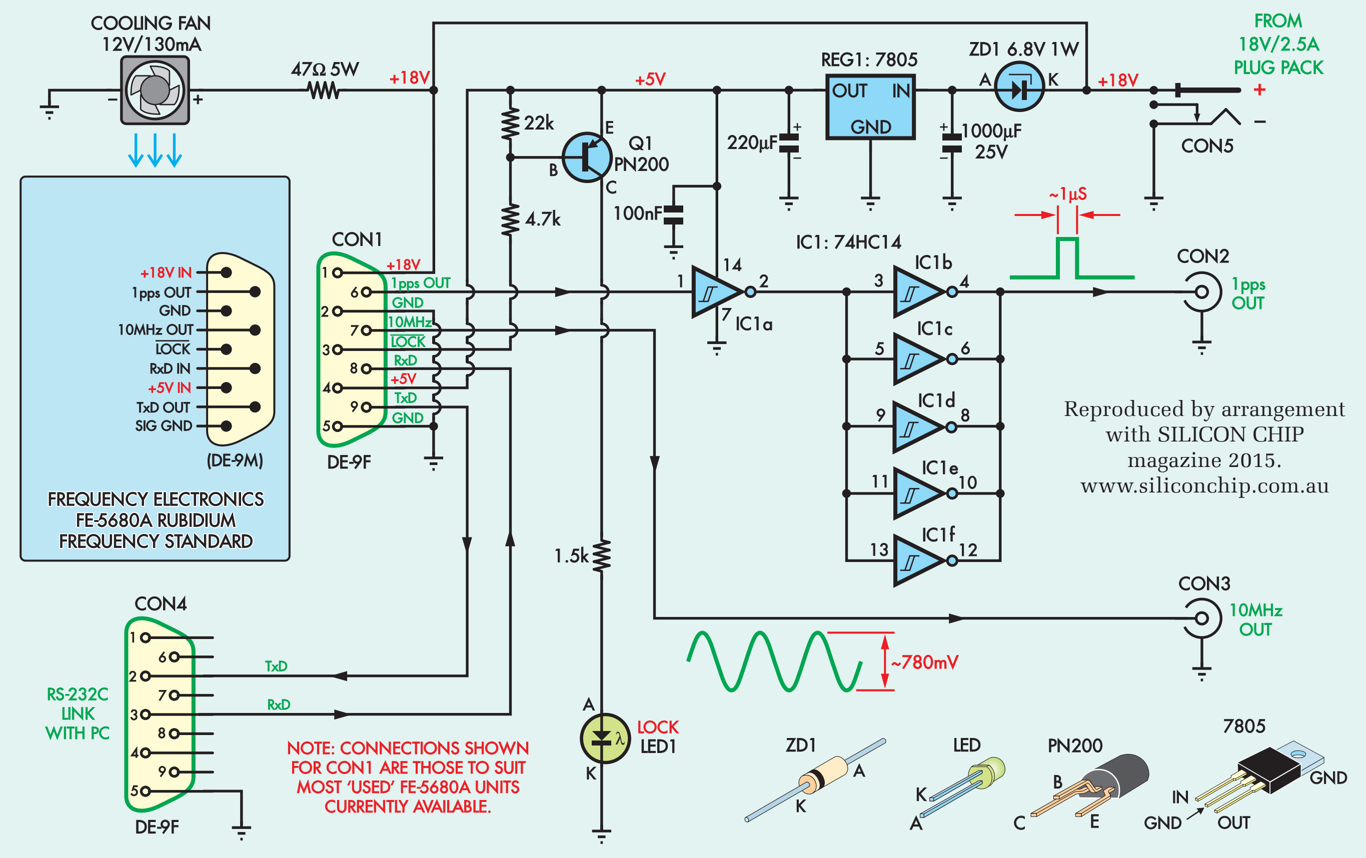
Building a test rig

It was now time to set the FE-5680A up as a working frequency and time reference. The first step was to build a test rig using some pieces of 4mm-thick sheet aluminium (see photo). There's a bottom plate to act as a heatsink for the FE-5680A, plus a back-plate to support the 12V fan and a small 'breakout board' for the power supply, lock indication and interfacing circuitry. There's also a smaller front-plate to support a DE-9F serial port connector, plus BNC sockets for the 10MHz and 1pps (one pulse per second) outputs. It's utilitarian, but it works (you could also build it into a case).

The circuit for the complete FE-5680A test rig is shown in Fig.2. The FE-5680A itself is shown as a blue rectangle at centre left and all the connections to it are made via DE-9F connector CON1. As shown, the TxD and RxD connections on pins 8 and 9 are fed directly through to DE-9F connector CON4 on the rig's front panel.

CON4 is for connecting the test rig to a PC. However, PCs and laptops no longer have an RS232 interface, I have designed an *RS232-to-USB Interface* and that device is described elsewhere in this issue. This can not only be used with the rubidium frequency standard but can be used anywhere a legacy instrument with an RS232 interface needs to be hooked up to the USB port of a current-model PC.

Getting back to Fig.2, the FE-5680A's 10MHz output from pin 7 of CON1 is fed directly to CON3, one of two BNC output connectors on the front panel. The rest of the connections on CON1



RUBIDIUM FREQUENCY/TIME STANDARD TEST RIG

Fig.2: the circuit for the complete test rig, including the breakout board. A 74HC14 hex Schmitt inverter (IC1a-IC1f) is used as an output buffer for the 1pps output from the FE-5680A rubidium standard, while transistor Q1 buffers the LOCK output to drive lock indicator LED1. An 18V plugpack supply powers both the FE-5680A and its cooling fan, while Zener diode ZD1 and regulator REG1 derive the 5V supply for IC1, Q1 and the logic inside the FE-5680A.

are taken to the external breakout PCB at the back of the test rig.

As shown, pin 1 is connected to a +18V supply rail, which is fed into the breakout PCB via CON5 (ie, from the external +18V plugpack). And pin 4 is connected to the +5V supply rail provided by REG1, a 7805 3-terminal voltage regulator, which is fed from the plugpack via series zener diode ZD1.

ZD1 is used to drop the input voltage by about 6.8V so that REG1 doesn't dissipate too much power. The 12V cooling fan is powered from the +18V rail via a 47Ω 5W series dropping resistor.

There are two 'signal processing' circuits on the breakout PCB, both quite straightforward. One is a simple buffer using PNP transistor Q1 to drive LED1 as a LOCK indicator.

As shown, Q1's base is connected to pin 3 of CON1 via a 4.7kΩ resistor, so that the transistor is held off whenever the FE-5680A holds its LOCK output high. Conversely, when it pulls this output low to indicate that it has locked, Q1 turns on and LED1 lights.

The remaining circuitry on the PCB involves IC1, a 74HC14 hex Schmitt inverter. This is used as a buffer for the FE-5680A's 1pps output which appears at pin 6 of CON1 when the unit is locked (note: a buffer is needed because the FE-5680A's 1pps output has very little drive capability).

One of the six inverters is used at the input to minimise the loading and this then drives the five remaining Schmitt inverters in parallel to provide increased drive capability, while also re-inverting the pulses. This double inversion inside IC1 does introduce a small propagation delay, but this is no more than about 40ns, so it doesn't matter.

The output pulses from IC1b-IC1f are fed directly to CON2, the second BNC socket on the test rig's front panel.

So there it is: a simple test rig which can be used to bring a retired FE-5680A rubidium-vapour frequency and time standard back to life. By making some relatively minor changes (eg, to cater for different connector pin-outs), it could also be used to resurrect other rubidium vapour standards.

Building the breakout PCB

The breakout circuit is built on a PCB coded 04105141 and measuring 102 × 38.5mm. Fig.3 shows the assembly details.

No particular order need be followed when installing the parts on the PCB – just be sure to install the polarised parts with the correct orientation. It's a good idea to mount the 5W resistor slightly proud of the PCB, to allow the air to circulate beneath it for cooling.

Once the assembly is complete, it can be attached to the rear aluminium end panel using a couple of right-angle brackets. REG1's tab is then fastened to this panel using an M3 × 10mm machine screw, nut and lockwasher, to provide heatsinking. The fan is also

fitted to this end panel (after making a matching cutout) so that it blows air across the FE-5680A rubidium standard mounted on the base.

The DE-9F connector and the two BNC output sockets go on the front plate of the test jig, as stated previously.

Tuning offset

As mentioned earlier, even when a rubidium-vapour standard like the FE-5680A warms up and 'locks to rubidium', its output frequency will not be *exactly* equal to 10MHz. That's because of the many complex parameters controlling the resonant frequency of the resonance cell – close to the theoretical figure of 6.8346826128GHz but not exactly so. And the actual frequency also drifts very slowly with time. Because of this and regardless of whether the standard has been languishing unused on a shelf or running for many months, it's generally necessary to program the standard's internal frequency synthesiser. That's done to bring its output frequency as close as possible to the magic figure of 10,000,000.0000Hz.

With the FE-5680A and most other Rb-vapour standards made in the last 15 years or so, the internal frequency synthesiser is a DDS (direct digital synthesiser). As previously stated, this is programmed by sending an offset number to it from a PC via its RS232C port.

The offset is generally a 32-bit binary number, which is sent to the standard as a signed 32-bit integer (usually as eight hexadecimal digits), preceded by a short command. In the case of the FE-5680A, there are two commands to change the offset – one to do so temporarily and the other 'permanently' by saving the new offset in its EPROM.

As shown in the command table at the bottom of Fig.1, there's also a third command which allows the PC to request the FE-5680A's current offset figure.

The fact that the offset programming number is a signed 32-bit integer means that the number can have any hexadecimal value between 7FFFFFFF (= +2,147,483,647), through zero (00000000) and down to 80000000 (= –2,147,483,647). And since the significance of a single bit of the offset programming number is stated as 1.7854 × 10^{-7}Hz, this becomes the setting resolution. In other words, the frequency offset can be programmed to any figure

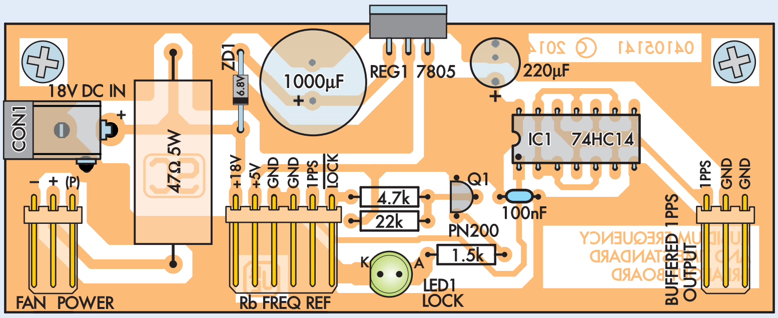
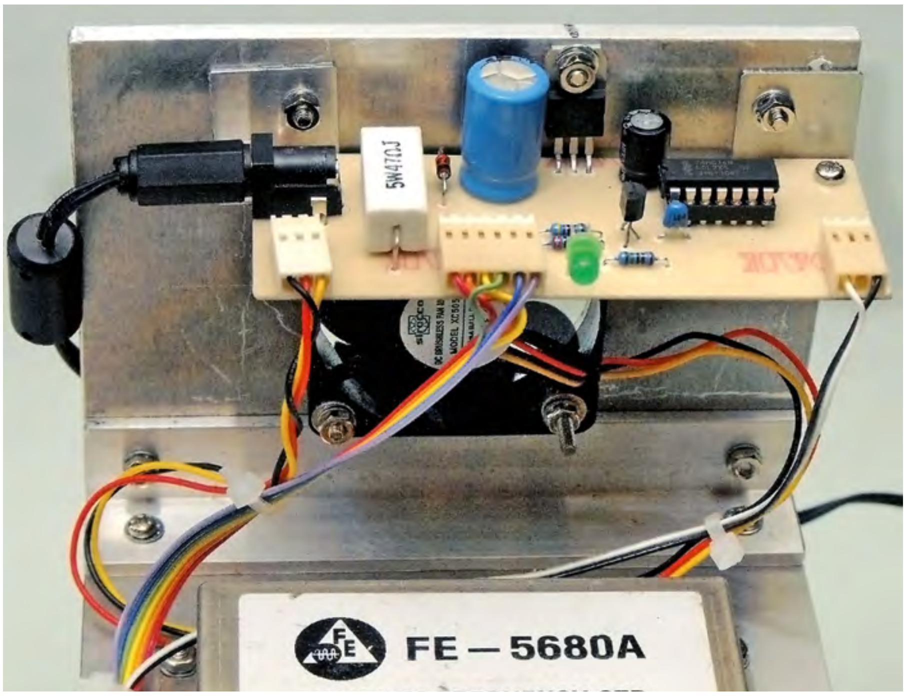


Fig.3: install the parts on the breakout PCB as shown here, taking care to ensure that all polarised parts are correctly oriented. Note that REG1's tab must be fastened to the metal end panel of the test jig for heatsinking.



Here's a closer view of the author's breakout board, mounted above the cooling fan on the rear plate of the test rig. REG1's mounting tab is screwed to the rear plate as well, to provide adequate heatsinking.

between +383Hz and –383Hz, in increments of 1.7854 × 10^{-7}Hz. That's a pretty good method of fine tuning, isn't it?

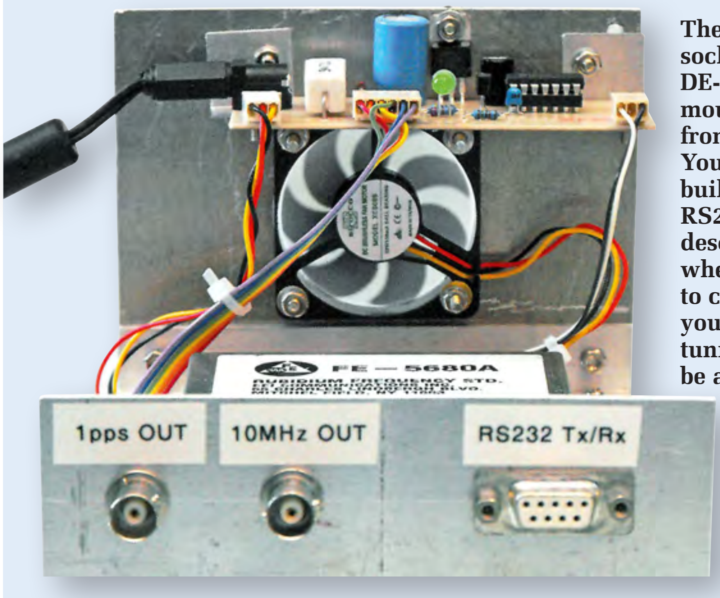
Of course, just how closely you'll be able to coax the output frequency to the ideal 10.000,000,0000MHz will depend mainly on the accuracy and resolution of your measurement set-up. If you can only measure down to 0.1Hz, that will be as close as you'll be able to go. It's a good example of the old adage that you need a really accurate clock to check another really accurate clock.

In my case, I was able to use the *12-Digit 2.5GHz Frequency Counter* described in the January and February 2014 issues of *EPE*. This can measure the frequency with a resolution down to 0.001Hz (1mHz) using the internal gating ranges and down to 0.0001Hz (100µHz) using an additional external ÷10 timebase divider.

But this is only feasible because I also have a source of 1pps timebase pulses which have excellent accuracy and stability in both the short and long term: a Stanford Research Systems PRS10 Rubidium Standard.

By using my 12-digit counter with this fancy external timebase set-up, I was ready to begin searching for the correct offset to program my FE-5680A, so that its output would move as close as possible to 10MHz (you may recall that when I first got it to lock, its frequency turned out to be 9,999,999.992Hz, ie, 8mHz low).

I had to do two things before this could be done, however. The first

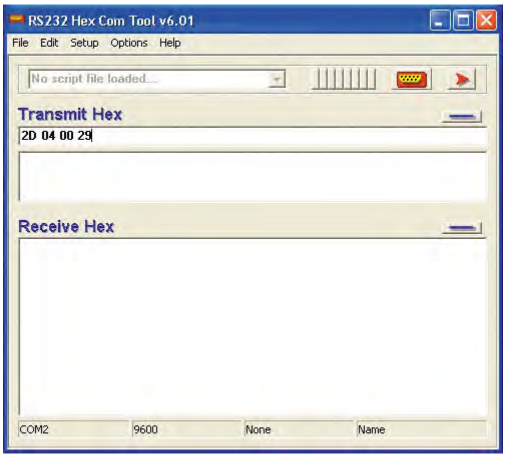


The two BNC sockets and the DE-9F socket are mounted on the front end-plate. You will need to build the USB/RS232C Interface described elsewhere in this issue to connect it to your PC so that the tuning offset can be adjusted.

job was to make up a USB/RS232C interface so that I could hook up the FE-5680A to the PC that I was going to use, as my PRS10 standard was already connected to the PC's one and only legacy RS232C port. That's one of the reasons why I developed the USB/RS232C interface described elsewhere in this issue of *EPE*.

Once that had been done, I then needed a 'serial terminal' program that would run on Windows XP SP3, communicate via a USB virtual COM port and preferably also allow me to send and receive messages in hexadecimal to make things easier (hex is a lot easier than straight binary).

After spending quite a bit of time downloading and trying out a number of freeware terminal programs, I finally settled on a program called 'RS232 Hex Com Tool v6.01', written by a firm called Virtual Integrated Design (VID). A free demo version of this can be downloaded from VID's website (see the links panel) but it closes down after



The main window of VID's RS-232 Hex Com Tool v6.01, a serial terminal application which runs under Windows but lets you transmit and receive data in hexadecimal – as you can see from the characters in the upper Transmit box. It's easy to set up and use to send commands to a rubidium standard like the FE-5680A.

about three minutes of operation and must be started up again if you want to use it for another three minutes – a bit irritating.

After you have used it for a short time, you'll probably want to purchase the full registered version. This is sold online for about $US40, via another firm called SWREG Inc (see the links panel again).

About the only thing that this terminal program doesn't do for you is work out the special 'exclusive OR checksum' that the FE-5680A needs after the data bytes are sent to it in the two change offset commands. Still, if you're only sending change offset commands with fairly small numbers (as we are here), it's not all that hard to work out the checksum yourself.

Doing it

At this stage, I was ready to try re-programming my FE-5680A with an offset which would bring its output frequency as close as possible to 10MHz. First off, I hooked everything up and launched the RS232 Hex Com Tool program. Then I sent the FE-5680A the command to discover its current offset, as stored in its EEPROM. As you can see from Fig.1, this command is '2D 04 00 29' and it must be terminated in a carriage return (0D hex).

The FE-5680A immediately responded by sending back '2D 09 00 24 00 00 00 00 00', terminated in another carriage return (0D hex). This showed

Handy Links

Frequency Electronics official FE-5680A product page:
http://www.freqelec.com/rb_osc_fe5680a.html

KO4BB's FAQ for the FE-5680A Rubidium Frequency Standard:
http://ko4bb.com/dokuwiki/doku.php?id=precision_timing:fe5680a_faq

Time Nuts mailing list archives:
http://www.febo.com/pipermail/timenuts/ and also at
http://www.mail-archive.com/time-nuts@febo.com/info.html

FE-5680A Series Option 2 Technical and Maintenance Instructions:
www.ka7oei.com/10_MHz_Rubidium_FE-5680A.html
www.guido_speer.de/Pub/images/Rubidium/5680A_TECH_MANUAL.pdf

Another good source for info on precise frequency and time:
http://leapsecond.com/

To download a free demo version of RS232 Hex Com Tool v6.0:
http://www.rs232pro.com/

To buy and download a full (registered) version of RS232 Hex Com Tool v6.0:
Either go to http://www.rs232pro.com/ and click on the 'registered' link, or go directly to https://usd.swreg.org/soft_shop/47653/shopscr6.shtml

Partial digital schematic (V0.3) of the FE-5680A:
http://www.rhodiatoce.com/pics/time-nuts/FE-5680A/FE-5680A_schematics_v0.3.pdf

Parts List

1 FE-5680A rubidium frequency standard (see text)
1 PCB, available from the *EPE PCB Service*, code 04105141, 102 × 38.5mm
1 12V cooling fan
2 DE-9F D-sub female sockets (CON1, CON4)
2 panel-mount BNC sockets (CON2, CON3)
1 2.5mm PC-mount DC power socket (CON5)
2 3-way right-angle locking (polarised) headers, PC-mount
2 3-way locking header plugs
1 6-way right-angle polarised pin header, PC-mount
1 6-way locking header plug
1 14-pin DIL IC socket
1 18V 2.5A plugpack supply
Aluminium panels and brackets to make test jig

Semiconductors
1 74HC14 hex Schmitt inverter (IC1)
1 PN200 PNP transistor (Q1)
1 7805 regulator (REG1)
1 6.8V 1W Zener diode (ZD1)
1 green 5mm LED (LED1)

Capacitors
1 1000µF 25V electrolytic
1 220µF 10V electrolytic
1 100nF MKT ceramic

Resistors (0.25W, 1%)
1 22kΩ 1 1.5kΩ
1 4.7kΩ 1 47Ω 5W 10%

Miscellaneous
Machine screws, nuts and washers, hook-up wire, cable ties

Here's the 'tweaked offset' output frequency of the author's FE-5680A rubidium standard, captured on the *12-Digit 1GHz Frequency Counter* using a home-brew time period divider to extend the gating time to 10,000 seconds. As you can see, the reading is 10,000,000.0000Hz, although the decimal point is not in the correct position.

DB-9 Or DE-9: Which Is Correct?

A 'DE-9' D-sub 9-pin connector is often mistakenly referred to as a 'DB-9' connector. The 'E' refers to the shell size. A 'DB-25' connector has a 'B' size shell but the common 9-pin connector is smaller and has an 'E' size shell.

This connector (regardless as to what you call it) is used for a variety of purposes. Two common applications are RS232/EIA-232 (serial) connections (including UPS cables) and a variety of video interfaces on the IBM PC.

me that the offset currently stored in its EEPROM and being used to set the DDS was zero – ie, 00 00 00 00, with a data checksum at the end of 00.

So now I knew that this particular FE-5680A, locked to rubidium and connected to my test rig, was providing an output of 9,999,999.992Hz with an offset of zero. That meant that I now had to try sending positive offset numbers to the FE-5680A to nudge its output frequency up by close to 0.008Hz, to reach the magic number of 10MHz.

This actually took longer than you might think, mainly because to get the measurement resolution, I had to have the counter set initially for a gating time of 1000 seconds (16.67 minutes). And that meant sending a new offset number and then waiting for just over half an hour (2 × 16.67 minutes) to see the result.

When I got close to the 'finish line', I then had to use the external timebase divider to give me a gating time of 10,000 seconds (2 hours and 47 minutes), to bring the counter resolution down to 100µHz. This now made for *really* slow progress, because after sending a new offset number, I then had to wait nearly six hours to see the result. In short, you have to be patient when adjusting the offset!

After some trial and error, I was finally able to find the offset number (00 00 02 F8) which brought the FE-5680A's output frequency to 10,000,000.0000Hz – as you can see from the photo of the frequency counter. After that, it displayed this impressive figure for over a week – with just the occasional appearance of a '1' in the least significant digit.

Of course, most readers won't have a second rubidium standard to serve as a timebase for the frequency counter. In that case, the best approach is to use the 1pps signal from a GPS receiver, eg, the *GPS 1pps Timebase* described in March 2014 or the *Deluxe GPS 1pps Timebase* described in April 2014. These are sufficiently accurate over long time periods to do the job.

A final word

So that's how I was able to get a low-cost 'retired' FE-5680A rubidium vapour standard going again, and set it up as a very useful frequency/time reference. It turned out that both units I purchased on-line were OK straight out of the box and there was no need to go though any of the tedious disassembly of the physics package or rejuvenation of the rubidium-vapour discharge lamp. I don't know whether I was fortunate or whether this would normally be the case with used units.

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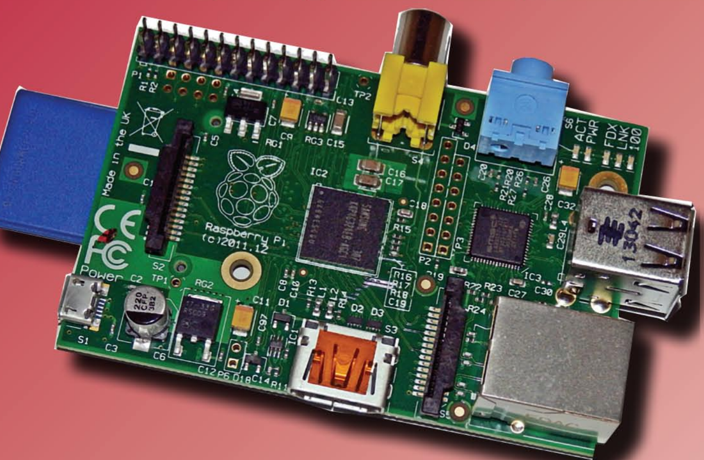

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Nature's way

TechnoTalk

Mark Nelson

Yes, this is the April issue, but don't go looking for any traps for the unwary in this article, however daft some of the stories may sound. This month, truth is truly stranger than fiction, as Mark Nelson now demonstrates.

IN PAST ARTICLES WE HAVE looked at earth currents, ball lightning (and of course ordinary lightning) as forms of naturally occurring 'free' electricity. As far as I know, nobody has managed to usefully capture this energy – of course, the odd unfortunate golfer has inadvertently captured it – but other forms of natural electricity may have a potential (get it?) for technology transfer.

PLEASED to make your acquaintance

Even though you might not have known it, plants, like almost all living organisms, have an internal communication system for responding to external stimuli. Whether they are exposed to sunlight, pollutants, nutrients or pests, plants react with a tell-tale electrical signal. Prince Charles, who was mocked for talking to plants in his garden, may have the last laugh now, as it is clear that plants have something to tell us. In fact, they have remarkable and significant sensing capabilities, whose electrical activity can be monitored and deciphered, much as human brain waves can be translated into machine-decipherable signals of non-verbalised patterns.

For this reason, the EU-funded PLEASED project, led by Dr Andrea Vitaletti at Rome University, was established to discover how plants might be used as biosensors. The project's name is an abbreviation of PLants Employed As Sensing Devices and no, this is truly not an April Fool's joke.

Smart solutions from the plant kingdom

This is by no means the first study of plants as bio-sensors, but previous researchers focused purely on studying individual plants in a controlled laboratory environment. This time, the focus is on actual outdoor scenarios (such as a forest or meadow) in which plants often receive uncontrollable and unpredictable stimuli. Readings from several plants are collected over a wireless network and integrated in a suitable way to obtain a consistent and global view of an environment of interest, using the plants as sensing and decision-making devices. The end goal is to create eco-friendly, self-sustainable and cost-effective plant-based solutions for tackling two key problems of the modern society: air pollution and the use of chemicals in organic agriculture. More information at: **http://pleased-fp7.eu**

Electric bacteria

Can you imagine a life form that feeds on electricity? No, we're not discussing the plots of sci-fi literature, but real Earth-based life forms that survive entirely on electrical energy in its purest form – without sugars, proteins or any other kind of nutrient.

Precisely this is the scenario portrayed by Catherine Brahic last year in *New Scientist* magazine, where she wrote: 'Unlike any other living thing on Earth, electric bacteria use energy in its purest form – naked electricity in the shape of electrons harvested from rocks and metals. We already knew about two types, Shewanella and Geobacter. Now, biologists are showing that they can entice more out of rocks and marine mud by tempting them with a bit of electrical juice.' She went on to quote Kenneth Nealson from the University of Southern California, Los Angeles, who explained that life, when you boil it right down, is based around the flow of electrons. 'You eat sugars that have excess electrons, and you breathe in oxygen that willingly takes them. Our cells break down the sugars, and the electrons flow through them in a complex set of chemical reactions until they are passed on to electron-hungry oxygen,' he stated.

Microbial nanowires

The article also quoted Lars Peter Nielsen from Aarhus University in Denmark, whose team discovered that tens of thousands of electric bacteria could join together to form daisy chains that carry electrons over several centimetres – a huge distance for a bacterium only three or four micrometres long. This enabled bacteria living, for instance, in seabed mud where no oxygen penetrates, to access oxygen dissolved in the seawater 'simply by holding hands with their friends'.

So what are the technology-transfer opportunities here? According to Nielsen, early research suggests that these nanowires conduct electricity roughly as well as the copper wires we use now, which could open up interesting research avenues involving flexible, lab-grown biocables. Kenneth Nealson (are these guys distantly related?) suggests that electric bacteria could be set to useful work in SPUDS, his name for 'self-powered useful devices'. The idea that biomachines could clean up contaminated groundwater or sewage spills, drawing their own power from their surroundings – amazing or what?

Daddy or chips?

For the little girl in the TV commercial (from the 1990s, long before you were born) promoting McCain Oven Chips, it was an either-or choice. Which did she like better, daddy or chips? In those days, having both was not an option, and until recently the same applied to light bulbs. The choice was either incandescent or LED (we'll exclude the detested compact fluorescent lamps).

Time moves on and now you can buy LED filament bulbs (just look on the Maplin, eBay or Amazon websites if you don't believe me!). These bulbs use LEDs as their 'filaments' and resemble their incandescent cousins very closely. Light is emitted from four LED filaments uniformly and evenly in all directions, instead of focusing it in a specific area in the way that many LED light bulbs do. The entire glass envelope' is clear, unlike the white 'egg cup' heatsink base of conventional LED bulbs, enabling these LED filament bulbs to mimic most of the shapes that were available in incandescent format. Consequently, these bulbs fit well into older lighting fixtures designed for incandescent bulbs, meaning these new LED filament lights allow homemakers to reuse their old and attractive light fittings.

There is of course no delay in illumination when switched on and the active electronickery is concealed unobtrusively inside the lamp base. The manufacturers state that the light produced by these bulbs is remarkably similar to natural light, but does not include any infrared or ultraviolet radiation. If you look around you will find versions producing daylight, warm white or golden glow colour temperatures. Too bad that I have already replaced all my old bulbs!

Win a Microchip MPLAB Starter Kit for Digital Power

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip MPLAB Starter Kit for Digital Power (#DM330017). This kit allows the user to easily explore the capabilities and features of the dsPIC33F GS Digital Power Conversion family. It is a digitally controlled power supply board that consists of one independent DC/DC synchronous buck converter and one independent DC/DC boost converter. Each power stage includes a MOSFET-controlled 5W resistive load. The kit features an on-board In-Circuit Debugger/Programmer via USB; LCD display for voltage, current, temperature and fault conditions and an on-board temperature sensor.

The Digital Power Starter Kit provides closed-loop proportional-integral-derivative (PID) control in the software to maintain the desired output voltage level. The dsPIC DSC device provides the necessary memory and peripherals for A/D conversion, PWM generation, analogue comparison and general purpose I/O, preventing the need to perform these functions in external circuitry.

DEC 2014 ISSUE WINNER
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HOW TO ENTER

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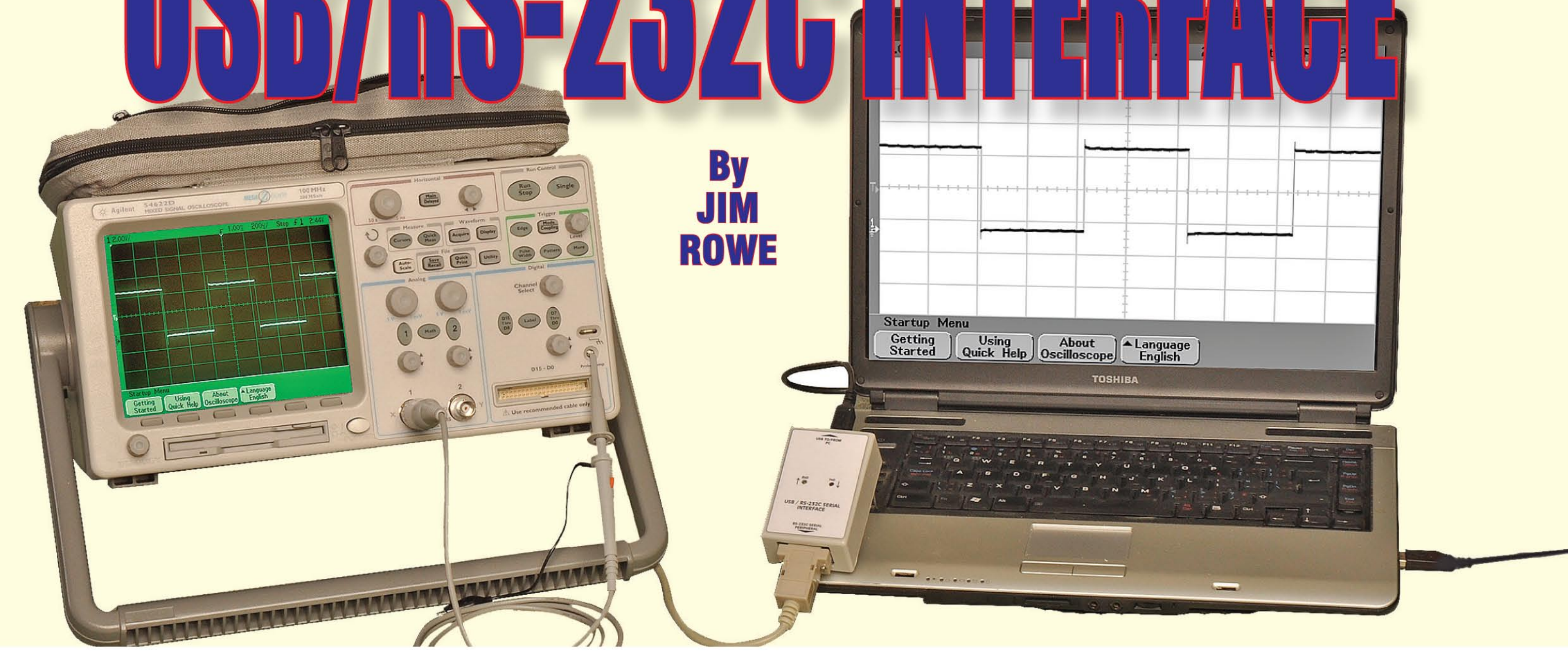
CLOSING DATE

The closing date for this offer is 30 April 2015

USB/RS-232C INTERFACE

By JIM ROWE



Want to connect an older test instrument or PC peripheral fitted with a 'legacy' serial RS-232C interface to your late-model PC or laptop? That is a real problem with today's PCs which only provide USB ports. Here is the solution: build this very small USB to RS-232C serial interface.

Many readers have test instruments, GPS receiver modules, Rubidium oscillators or PC peripherals which work perfectly well, but they can pose a problem when it comes to hooking them up to a current-model desktop or laptop PC.

That's because many older instruments and devices were fitted with what is now known as a 'legacy' serial RS-232C interface, while most recent PCs are only provided with USB ports.

Yes, we know you can purchase cheap USB-to-RS-232C interface adaptors. But many of these don't work very well – or don't work at all – with older equipment with RS-232C interfaces. Also, many of these gizmos are not compatible with Windows VCP (virtual com port) drivers and need to have a custom driver installed – which is often a problem in itself.

Cheap, not nasty!

That's why we've come up with this new interface, which can be built up at very low cost. Total cost, including the PCB, should be about £20 or less. And you should be able to assemble it in just a few hours.

All of the parts, including the input and output connectors, fit on a PCB which measures only 76 × 46mm. It fits neatly into the smallest jiffy box currently available – the UB5 size, measuring 83 × 54 × 31mm.

About the circuit

The complete circuit of the interface, shown in Fig.1, uses just two chips and not much else. At its heart is IC1, a Microchip MCP2200 'USB-UART Protocol Converter' chip, which seems to be rather similar to a PIC18F14K50 micro, but is hard-wired to perform USB/serial and serial/USB conversion. On the serial side it's coupled to the inverters inside a 74HC14 hex Schmitt trigger inverter device (IC2), acting as serial drivers and receivers.

Where's MAX?

And no, we have not coupled the MCP2200 to a MAX3232 or MAX3222 multi-channel RS-232C driver/receiver device – to give the circuit 'full spec' bipolar RS-232C compatibility. Our first prototype did use that approach, but we found that it would not operate reliably with a number of instruments and devices. These turned out to have a serial interface which provided only 'unipolar' 0V/+5V signal swings.

This was done (a) to save money and (b) because just about all of the serial ports on earlier PCs would interface quite reliably with these signals, even though they were nominally designed to provide and accept bipolar signal swings, ie, signal swings meeting the full RS-232C specification, which specified from –5V to –15V for a mark or '1', and from +5V to +15V for a space or '0'.

So, after quite a bit of testing and experimentation we decided to replace the MAX3222 driver/receiver device with the 74HC14 shown in Fig.1. It effectively goes back to the old unipolar 'watered down RS-232C' configuration, but we have found it to work reliably with all of the 'legacy' serial ports we've been able to try it with, including those with 'true RS-232C' ports as well as those with the 'watered down' approach.

We can't guarantee that it will work reliably with ALL equipment fitted with a 'true RS-232C' port, because there may be some gear out there with a finicky RS-232C driver/receiver chip which won't recognise unipolar signals. But we suspect these are few and far between, especially these days.

It's also worth noting that while the original 'full spec' bipolar signals were designed to give reliable operation over quite long cables (up to at least 15m), the unipolar 0V/+5V signals of this *Interface* won't be capable of anything like this. But since this *Interface* is intended mainly to connect 'legacy' instruments and equipment to a nearby PC, this shouldn't be a problem.

Returning to the circuit of Fig.1, you can see that four of the inverters inside IC2 are used as drivers, two in parallel for the transmit data (TxD) line and the other two in parallel for the Ready-to-Send (RTS) handshaking line. The remaining two inverters are used as receivers, for the Receive data (RxD) line and the Clear to Send (CTS) handshaking line.

So what's the purpose of the 1kΩ series resistors in those 'receive' signal lines, and also for diodes D1-D4? These components are included to allow the inputs of the 'receiver' inverters inside IC2 to handle both true-RS-232C bipolar swing signals as well as unipolar signals. The 1kΩ resistors limit the current flow, while the diodes ensure that the inverter inputs are 'clamped' to a maximum DC input level of +5.6V and a minimum level of –0.6V.

The circuitry around IC1 is quite straightforward. Pins 18 and 19 are the USB data lines and these connect directly to pins 2 and 3 of USB connector CON1.

Pins 2 and 3 of IC1 are the input and output pins for its internal clock oscillator, which runs at 12MHz as a result of connecting crystal X1 and the 33pF and 15pF capacitors. The oscillator runs at 12MHz because it connects to an internal PLL (phase-locked loop) which effectively multiplies the clock by four, to achieve the 48MHz needed by its USB 2.0 interface engine.

Pin 17 of IC1 is its V_{USB} pin, which needs to be provided with a 470nF bypass capacitor for correct USB enumeration.

Pins 5 and 6 are configured in this application to drive LEDs 1 and 2, which blink to indicate activity on the serial RxD and TxD lines.

By the way, the MCP2200 is configured from your PC, using a small (freeware) configuration utility. This can be used to configure the MCP2200 in terms of baud rate, data format and so on. We'll describe this in detail later.

No external power is needed for the circuit as it is powered from your PC via the USB cable and pin 1 of connector CON1. Typical current drain varies between about 18mA and 29mA, depending on the data being sent and received; well within the 100mA limit.

Construction

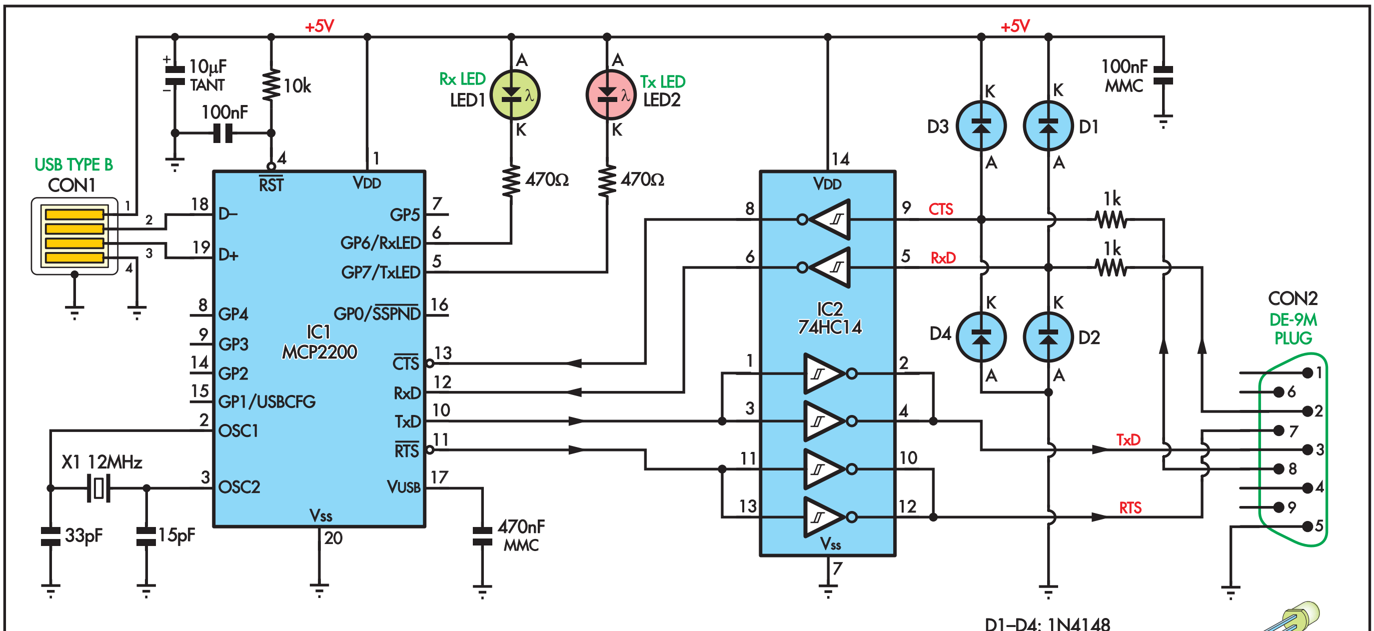
As you can see from the photos and the overlay diagram of Fig.2, all of the components used in the interface are mounted on the top of a small double-sided PCB coded 07103141 and measuring 76 × 46mm. This has USB connector CON1 at one end and serial connector CON2 at the other.

The complete PCB assembly fits snugly into a UB5 jiffy box. It is used upside-down: the PCB is attached to the 'lid' of the box (which becomes the base), using four 15mm-long M3 machine screws with four 6mm-long untapped spacers and four M3 nuts to hold the PCB in place. The two activity LEDs protrude through matching 3mm holes in the 'base' of the box, which becomes its top.

There is only one SMD component in the project (IC1), which comes in a 20-pin SOIC package. I suggest you solder this to the top of the PCB before any of the other components, as this makes construction easier.

You can hold it in position using a pair of spring-loaded, self-closing tweezers or similar while you spot-solder diagonally separated pins (eg, pins 1 and 11, or 10 and 20) to their pads on the PCB. Then the tweezers can be removed to give you clear access while you solder the rest of the pins on each side.

If you do create an accidental solder bridge between adjacent pins, it's usually easy to remove the bridge using



USB TO RS-232C SERIAL INTERFACE

Fig.1: just two ICs and a handful of other components make up the interface.

The *Interface* is housed in a small jiffy box, small enough to fit in the palm of your hand. There's no battery because it is powered from the USB port that it's connected to.

narrow solder-wick (pressed against the pins concerned using the tip of your soldering iron).

All of the remaining components are through-hole parts, which can be fixed to the PCB in the usual way. Fit the resistors first, followed by the capacitors, taking care with the polarity of the 10µF tantalum, which is the only polarised capacitor.

Then fit crystal X1, followed by diodes D1-D4 – using diagram Fig.2 to guide you regarding their polarity.

Next fit IC2, the pins of which can be either soldered directly to the pads under the PCB or plugged into a 14-pin DIL socket soldered into the PCB. Then both CON1 and CON2 can be fitted, noting that each connector is held onto the PCB via a pair of lugs which are soldered to the copper underneath in addition to the actual connection pins.

The final components to be added are LED1 and LED2, which are mounted vertically above the PCB with their leads left at almost full length, so the underside of each LED body is about 16mm above the top surface of the PCB. Make sure you fit the green LED in the correct position for LED1 and the red LED in the LED2 position, and also make sure that they are both oriented with their longer anode lead to the right (towards CON2) as shown in Fig.2.

Box drilling

Your PCB assembly should now be complete, ready for mounting to the box lid. But first you'll need to prepare both the box and its lid, by drilling and cutting the various holes shown in Fig.3.

There are eight holes in all – four in the lid for mounting the PCB, two in the 'base' of the box for the two activity LEDs, and a rectangular hole at each end for access to connectors CON1 and CON2.

Assembly

After you have drilled and cut all of the holes and finally removed any burrs, you should be ready to mount the PCB assembly inside the lid. This involves passing the four 15mm long M3 screws up through the holes in the lid, and fitting each one with an untapped 6mm long spacer.

The PCB assembly can then be lowered into position with the ends of the screws passing through the matching holes near each corner of the PCB. Then four shake-proof washers and M3 nuts can be fitted to the screws to hold the PCB in position.

If you'd like to give your *Interface* a 'front panel' like the one you can see in our photographs (mainly to identify LED1 and LED2), we have prepared the artwork which can be downloaded from the *EPE* website. This can be printed and then laminated in a plastic sleeve for protection and finally cut to shape and attached to the outer surface of the base of the box (which becomes the top) using thin double-sided cellulose tape.

The box can then be up-ended and lowered down over the PCB-and-lid assembly, oriented so that the end with the longer rectangular cut-out is at the CON2 end of the PCB. Make sure that the two LEDs pass up and just protrude through their matching holes. Then the four small self-tapping screws supplied with the UB5 box can be used to fasten the box and lid together, to complete the assembly.

You may also want to attach four small adhesive rubber or plastic feet to the lid/underside of the *Interface*, to ensure that the screw heads don't scratch any surface it's placed on.

Configuring the MCP2200

While there are no adjustments to be made to the *Interface* before it can be used, the MCP2200 USB-serial protocol converter chip (IC1) does need to be configured to suit your particular application.

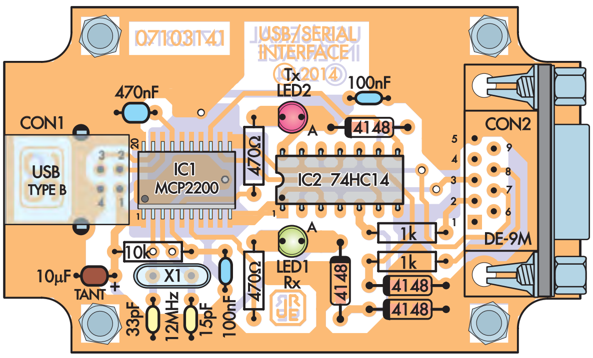
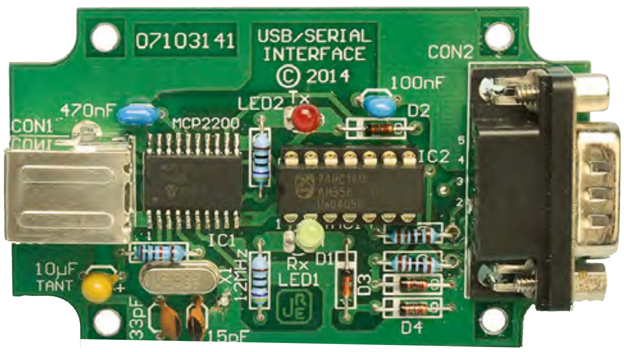


Fig.2 (left): the component overlay, with a matching same-size photograph at right.



As mentioned earlier, this is done by connecting the *Interface* to one of the USB ports on your PC and then running Microchip's freeware Configuration Utility.

When you first connect the *Interface* to a USB port on your PC (assumed to be running), Windows will respond by installing its standard 'virtual COM port' driver. You can then call up Device Manager (usually via Control Panel) and look under 'Printers and Devices' to make sure that you now have a 'USB serial port'. Otherwise you may need to download and install the Microchip Serial Port Driver from the link mentioned below.

Check its Properties to learn which COM port number it has been given, the data format it has set (8 data bits, no parity and one stop bit are usually best) and also check whether Windows is advising that it is 'working properly'.

Set the driver's baud rate to match that of the instrument/GPS receiver module/Rubidium oscillator or whatever you're going to be using the *Interface* to communicate with. This will probably be either 4800 or 9600 baud (bps) but you may need to check in its user manual to make sure.

Assuming this first step has gone smoothly, the next step is to download and install Microchip's custom MCP2200 Configuration Utility. This can be downloaded from their website by typing in this URL: **www.microchip.com/MCP2200.** Click on 'documentation and software', then scroll down until you find the MCP2200 Configuration Utility. It's a 5.3MB zipped file.

After unzipping, this provides a self-installing version of the MCP2200 Configuration Utility.

When you run this and then fire up the utility itself, you should see a window like that shown in Fig.4 – although

Parts List – USB/RS232C Interface

1 UB5 jiffy box, 83 × 54 × 31mm
1 PCB available from the *EPE PCB Service*, code 07103141, size 76 × 46mm
1 12.00MHz crystal, HL-49U/US (X1)
1 USB type B connector, PC-mounting (CON1)
1 DE-9 male connector, PC-mounting (CON2)
4 15mm long M3 machine screws, pan head
4 6mm long untapped spacers
4 M3 nuts with shake-proof washers
4 adhesive rubber or plastic feet (optional)

Semiconductors
1 MCP2200-I/SO USB 2.0 to UART protocol converter (IC1)
1 74HC14 hex Schmitt trigger inverter (IC2)
4 1N4148 100mA diodes (D1-D4)
1 3mm green LED (LED1)
1 3mm red LED (LED2)

Capacitors
1 10µF 16V tantalum electrolytic
1 470nF 50V multilayer monolithic ceramic (474 or 470n)
2 100nF 50V multilayer monolithic ceramic (104 or 100n)
1 33pF NP0 disc ceramic (33 or 33p)
1 15pF NP0 disc ceramic (15 or 15p)

Resistors (0.25W 1%)

1 10kΩ	(brown black orange brown or brown black black red brown)
2 1kΩ	(brown black red brown or brown black black brown brown)
2 470Ω	(yellow violet brown brown or yellow violet black black brown)

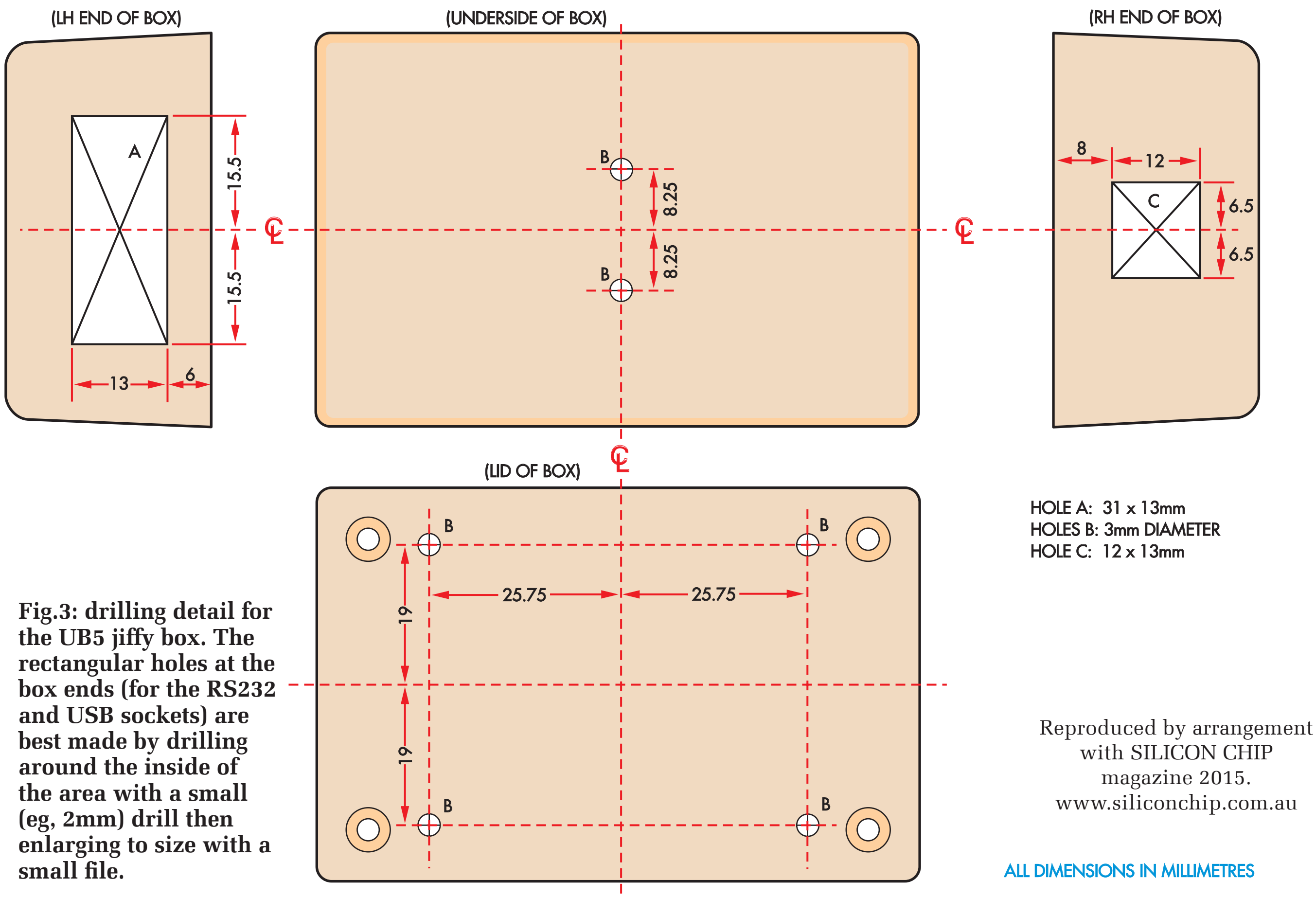


Fig.3: drilling detail for the UB5 jiffy box. The rectangular holes at the box ends (for the RS232 and USB sockets) are best made by drilling around the inside of the area with a small (eg, 2mm) drill then enlarging to size with a small file.

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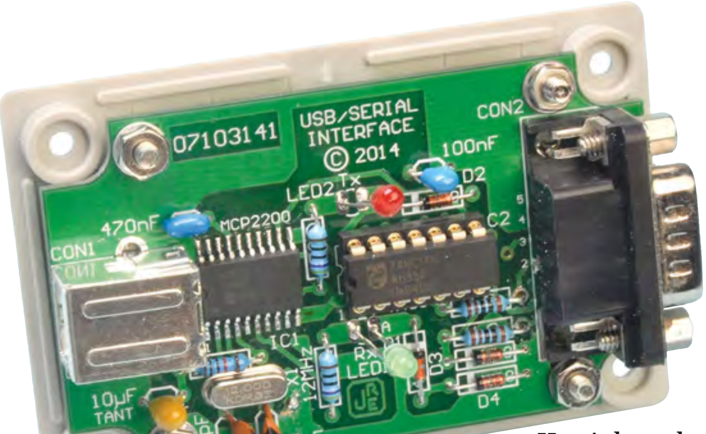

Here's how the PCB mounts on the lid of the box, which becomes the base...

you won't see any text as yet in the large 'Output' box. This box will be blank initially, while some of the smaller boxes may also have different contents.

Before you click on the 'Configure' button at bottom left, you'll need to ensure that the contents of all of these smaller boxes are as shown in Fig.4. You probably won't need to change the contents of the Manufacturer, Product, Vendor ID or Product ID boxes, nor will you need to click on the 'Update VID/PID' button.

But you may need to click on the check box next to the label 'Enable Tx/Rx LEDs', to display the tick as shown.

It's also possible that you may need to click on the check box next to 'Enable CTS/RTS pins', if the serial device you're going to be communicating with needs this kind of handshaking. But this is unlikely with most of the devices you'll want to communicate with using the *Interface*.

If the Baud Rate: text box is not showing the baud rate you want, click on the down arrow to its right to get the drop-down list box, and then select '4800' or '9600' or whatever baud rate you do need from the list. Then if the I/O Config: text box is showing something other than '00000000', click inside the box so that you can type in the correct '00000000' text string.

Similarly, if the Output Default: text box is not showing '11111111', click inside that box and type in that text string yourself.

Now turn your attention to the LED Function box at lower right, and if necessary click on the 'Blink LEDs' radio button if this isn't displaying the 'selected' bullet. Similarly, click on the '100ms' radio button so that it too is selected.

At this stage you should be seeing a display very much like that shown in Fig.4, apart from a blank output window. If this is so, you can now click on the Configure button at lower left. There should then be a brief pause while the Config utility 'does its thing' with the MCP2200 chip in your *Interface*; then the text shown in Fig.4 should appear in the Output window to show that the configuration has been done and your *Interface* is now communicating with the PC via the USB cable. You can then close the Config utility, because your *USB-Serial Interface* is now configured and ready for use.

What if you decide at a later time that you want to use the same *Interface* to communicate with a different serial device? That's not really a problem, because all you'll need to do is fire up the MCP2200 Configuration Utility again and use it to reconfigure the *Interface's* MCP2200 to suit the 'new' serial device. You'll be able to change the baud rate, disable the CTS/RTS pins if handshaking is not needed any more, and so on.

A few words about cables

That's about it as far as the *Interface* itself is concerned, but before closing we had better give some basic information regarding RS-232C serial cables and the ways in which they're wired. That's because it's not easy to buy this type of cable nowadays, so you may need to wire up one or more cables yourself.

Another possibility is that you may have one or two older serial cables, but are not sure how they're wired. This can be frustrating if you try using one to connect between the *Interface* and a particular device and find they won't 'talk to each other'.

First of all, most serial ports on older PCs used DE-9 nine-pin connectors rather than the DB-25 25-pin connectors originally used to interconnect RS-232C serial devices like teleprinters and dial-up modems with minicomputers and mainframes. So you'll probably only have to concern yourself with cables fitted with a nine-pin connector at each end.

The next thing to be aware of is that many 'RS-232C' serial devices didn't use 'hardware' handshaking at all. Instead of using any of the handshaking lines of the serial ports and cables, they implemented a simple software-driven handshaking protocol, sometimes called 'X-on/X-off'). As a result, these devices may not even need you to use a nine-conductor cable at all: just a stripped down or 'bare minimum' three-wire cable, with only the RxD and TxD data lines plus a ground line.

But be warned: even though the device itself may not need any of the handshaking lines, the software running

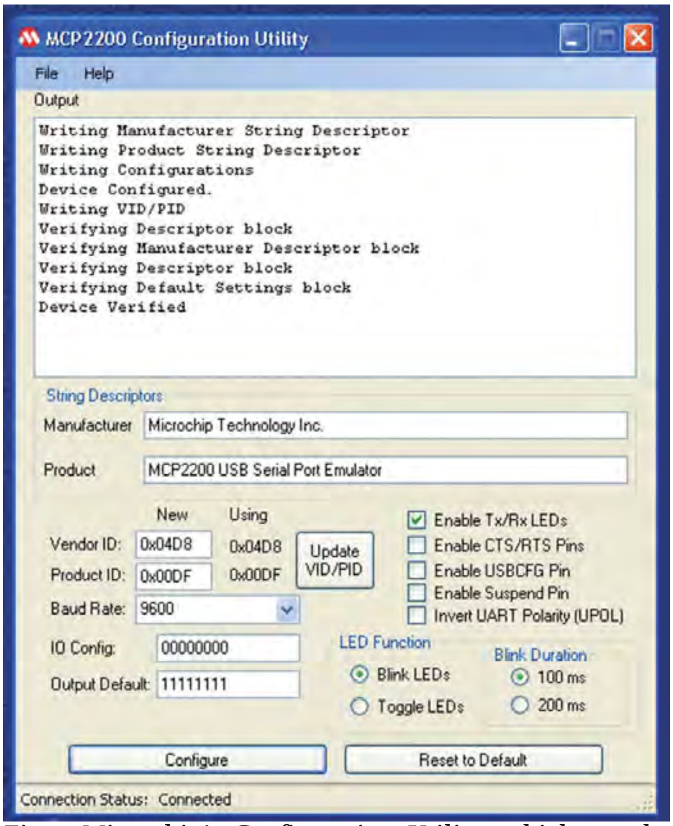

Fig.4: Microchip's Configuration Utility, which can be downloaded free of charge

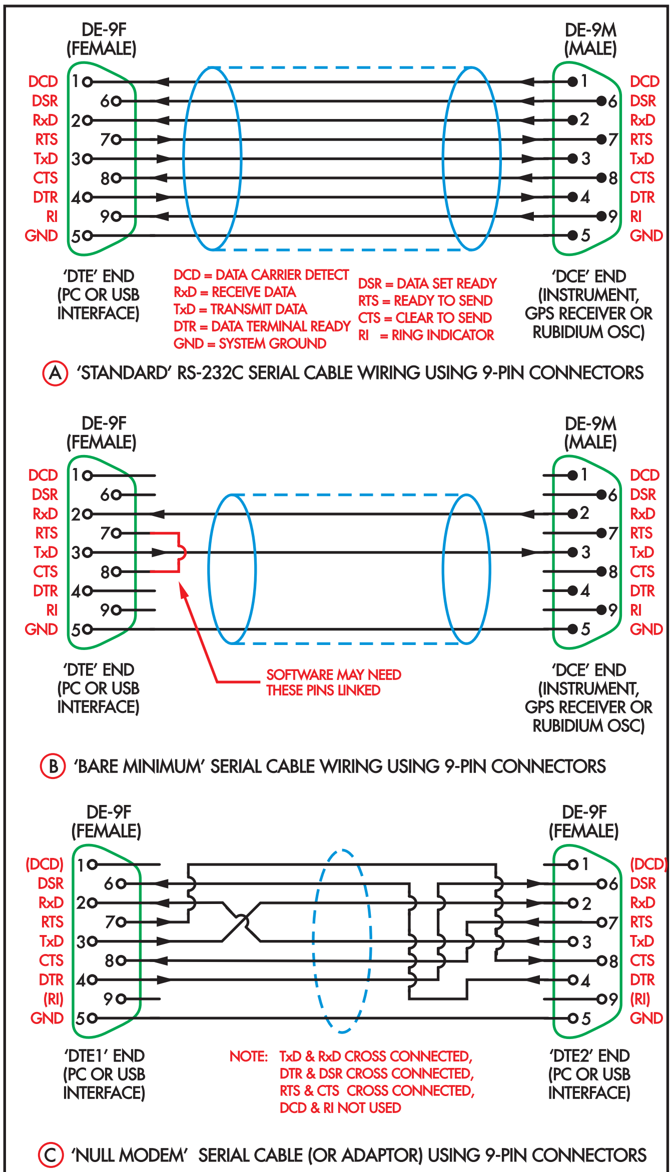

Fig. 5: various types of serial cables which may be required for the interface.

in your PC might need to be 'tricked' into thinking that the device is ready for action, by linking together some of the pins at the *Interface* end of the cable (the RTS and CTS pins, for example). Otherwise the software may regard the device as 'not present' or 'busy'.

Right, now take a look at Fig.5, which shows in (a) the way a standard RS-232C serial cable was wired up using 9-pin connectors. You can make up this kind of cable very easily using IDC-type DE-9 connectors and a length of standard IDC ribbon cable, because all of the wires have a 'straight through' connection – pin 1 to pin 1, pin 2 to pin 2 and so on.

The main thing to remember is that the PC or *Interface* end of this cable (the so-called 'DTE' end, standing for 'data terminal equipment) has a female (DE-9F) connector, while the other end (the 'DCE' or 'data comms equipment' end) is usually fitted with a male (DE-9M) connector.

This type of cable should be fine for connecting the PC (via the *Interface*) to many types of 'legacy' serial device. But just so you'll be aware of the options, take a look at Fig.5(b). This shows the wiring of a 'bare minimum' three-wire cable, which only provides the RxD and TxD data lines plus the ground line. You should be able to use this much simpler type of cable to communicate reliably with many of the 'legacy' devices using our new *USB-serial Interface* – although you may find it necessary to link pins 7 (RTS) and 8 (CTS) of the connector at the PC/*Interface* end, to keep the software 'happy'. That's why the diagram shows the link between these pins in red.

Finally, Fig.5(c) shows the wiring for a so-called 'null modem' serial cable or adaptor. Quite possibly you won't need to worry about this type of cable/adaptor, because it was really only used to allow two PCs to be hooked up to each other directly via their serial ports, for exchanging data files etc (although we did need to do this to connect the old Agilent scope shown in the opening photo).

As you can see, this type of cable/adaptor has a female DE-9 connector at each end. It also has 'crossover' connections linking the RxD and TxD data pins, the DTR and DSR pins and also the RTS and CTS pins – so the 'outputs' at each end connect to the 'inputs' at the other.

A cable wired up this way won't work if you try to use it to connect your PC and *Interface* to a 'legacy' device like a test instrument, a GPS receiver module or a rubidium oscillator. You'll need to either use a different cable or rewire it to remove the crossover connections.

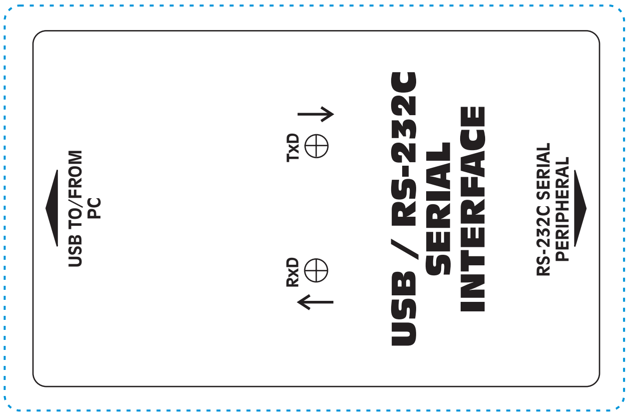

Fig.6: this front panel artwork (which actually attaches to the bottom of the box) can also be downloaded from the *EPE* website.

Part 2 – by John Clarke

Building our new Super Smooth, Full-range, 10A/230V Speed Controller for Universal Motors

Last month we described the features and circuit details of our new *Speed Controller*. This month, we move on to construction and troubleshooting.

This new Motor Speed Controller is constructed on a single PCB, coded 10102141 and measuring 112 × 141mm. It is housed in a diecast metal case measuring 171 × 121 × 55mm. A front panel label measuring 168 × 118mm is attached to the lid of the case.

The PCB includes cutouts to match the shape of the case and a cutout for the IEC input connector.

Before construction, you need to check what bridge rectifier is being used for BR1. This can be either a PCB mounting type or one that has spade terminals – the construction varies depending on which type is used. There is no best choice.

For the spade terminal bridge, extra wiring is involved, whereas with the PCB-mounted bridge, there is some filing required to remove the two ribs that prevent the bridge mounting flat against the side of the case.

Also, decide if you prefer having the feedback control potentiometer (VR2) mounted on the front lid or whether you will use the internal trimpot (VR3).

Beginning construction

First, check the PCB for any etching problems (bridged or broken tracks, etc) and wrongly-drilled holes.

We do not expect that there will be any problems with PCBs supplied by the *EPE PCB Service* or with those supplied in kits. These are of high quality and are solder masked, screen-printed and shaped with the required cutouts.

However, if there are any problems, repair these as necessary. Similarly, if the cut outs in the sides of the PCB have not been shaped, they should be cut and filed before any components are assembled.

Check that the PCB fits into the case before starting assembly.

Following the overlay diagram shown in Fig.9, first solder in the resistors, except the 0.01Ω resistor, using the colour code table and/or a digital multimeter, to ensure you have the right resistors in the right places.

When inserting diode D2 and ZD1 take care with their orientation. Diode D1 is installed later.

We used an IC socket for IC1 only. Be sure to install the IC socket and the ICs the correct way around, with the notch facing the direction shown on the overlay. Also, ensure IC2 and IC3

This is NOT a project suitable for beginners or the inexperienced!

This project should only be attempted by constructors with extensive experience in mains-powered circuits and with the knowledge necessary to get it going if something is wrong.

This circuit connects directly to the 230VAC mains and most components are floating at this voltage.

Inadvertent contact with a live circuit could prove lethal.

Do not operate the circuit with mains connected, without the case lid being secured with all six screws provided. Always remove the mains lead from the IEC socket before removing lid.

Low-voltage trouble-shooting tips are provided in this article.

We reiterate: do not attempt to build this speed controller if you do not have the experience necessary to do so.

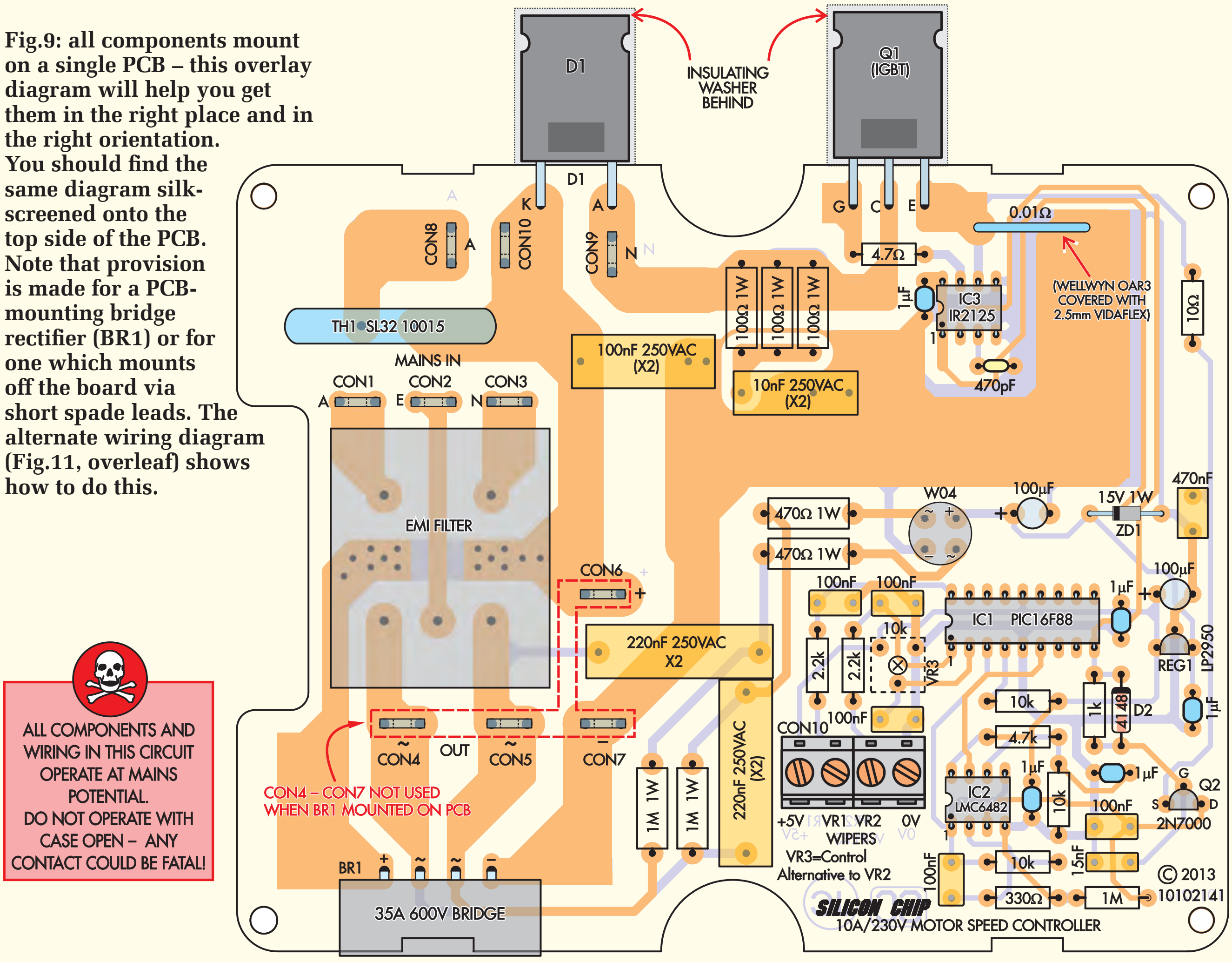

Fig.9: all components mount on a single PCB – this overlay diagram will help you get them in the right place and in the right orientation. You should find the same diagram silk-screened onto the top side of the PCB. Note that provision is made for a PCB-mounting bridge rectifier (BR1) or for one which mounts off the board via short spade leads. The alternate wiring diagram (Fig.11, overleaf) shows how to do this.

are placed in their correct position. REG1 and Q2 can now be inserted, again taking care to place each in its correct position. Q1 is installed later.

Capacitors can be installed next, using the capacitor table. It shows the various codes that are used to indicate the capacitance values of the MMC, MKT polyester, and ceramic capacitors.

The electrolytic capacitors have their value directly marked but must be oriented with the correct polarity, as shown. So too must the small diode bridge, BR2, which can be soldered in now, along with the 4-way screw terminal. It's made up of two 2-way terminals dove-tailed together before being inserted and soldered in place. The lead entry side is toward the lower edge of the PCB.

The 0.01Ω resistor can now be installed. It has a 40mm length of 2.5mm diameter Vidaflex heat-resistant sleeving slid over it before inserting into the PCB holes.

VR2/VR3 choices

As discussed last month, VR2 is optional but gives front-panel control over feedback. Note that if VR2 is going to be used, you should include either VR3 or a link in its place on the PCB to prevents input AN3 from floating.

Solder in VR3 or place a short wire link (using a length of resistor lead off-cut) between the central wiper connection and one of the end pads (either one) for the VR3 position.

Next are the spade connectors at CON1-CON3 and CON8 and CON9. Spade connectors are also required at CON4-CON7 if BR1 is a spade terminal type.

Install the EMI filter and also the NTC thermistor. The PCB-mounted bridge for BR1 can be mounted now if this is used. This sits as low as pos-

Features

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- Over-current limiting
- Soft starting
- NTC Thermistor for initial surge current limiting
- Fuse protection
- Rugged case with interference suppression included

sible on the PCB before being soldered in place.

D1 and Q1 are the last components to be soldered to the PCB. Solder them in so their metal flanges are towards the edge of the PCB and their full length leads are extending about 1mm below the PCB.

Mounting the hardware

The front panel artwork can be copied and used as a marking-out template. Note that it does not have a hole position for the main earth bolt, which can be mounted anywhere it doesn't interfere with anything else.

Also shown is a marking-out diagram for the end wall of the case (Fig.12).

The IEC connector mounts with about a 4mm gap from the base of the case to the bottom of the IEC connector. The hole is made by drilling a series of small holes around the perimeter of the desired shape, knocking out the piece and filing to shape. The earth screw hole is 4mm in diameter.

The EMI filter mounts directly on the PCB and assists greatly in removing switching noise generated by the circuit.

If you are using the PCB-mounted bridge rectifier, file away the two ribs on the side of the case that prevent the bridge mounting flat.

Insert the PCB into the case, noting that the leads for D1 and Q1 must be kinked outward a little so that the metal flange of each device is parallel to and in contact with the side of the case. Mark the mounting hole positions for diode D1, IGBT Q1 and bridge rectifier, BR1.

For the quick connector terminal bridge rectifier type, this is mounted side on against the case side.

The holes required for mounting Q1 and D1 are 3mm, while a 4mm hole is required for the bridge rectifier.

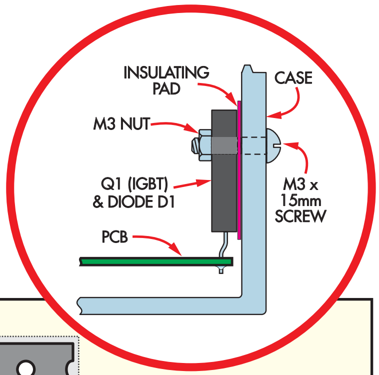
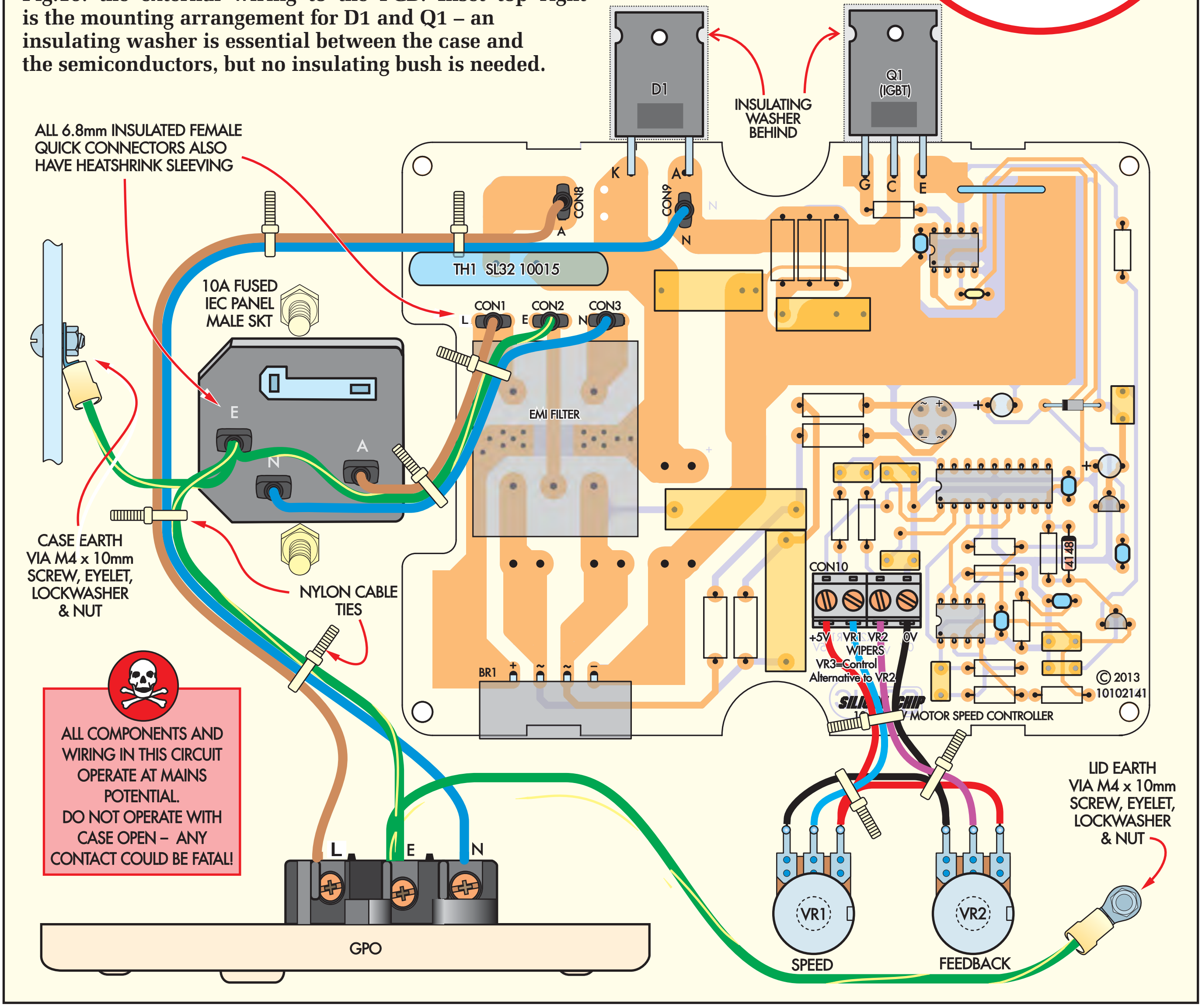


Fig.10: the external wiring to the PCB. Inset top right is the mounting arrangement for D1 and Q1 – an insulating washer is essential between the case and the semiconductors, but no insulating bush is needed.



Holes are also required in the lid for VR1 and VR2 (if required) and the earth terminal, with a cutout and holes for the mains general purpose outlet (GPO).

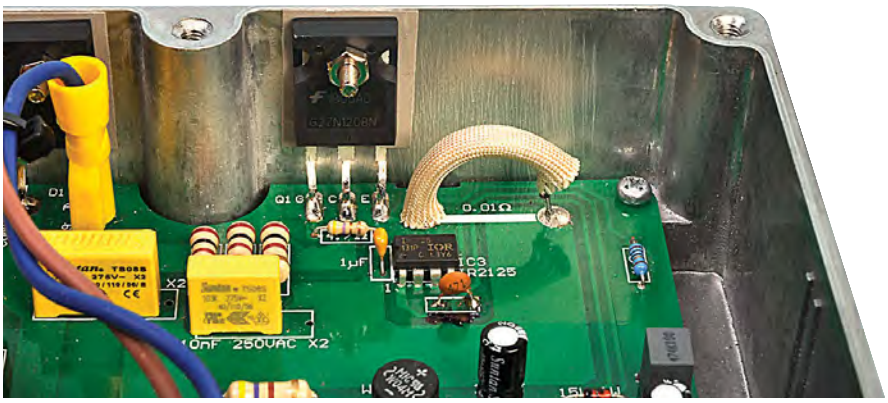
There are locating spigots on both VR1 and VR2 which prevent the potentiometer body from rotating when the knob is turned. The holes for these (so the spigot will be captive in the hole) do not need to be drilled fully through to the front of the lid panel.

All holes should be de-burred on the inside of the case with a countersinking tool or larger drill to round off the sharp edges. For D1 and Q1, the edges must be rounded to prevent punch-through of the insulating washers.

Attach the PCB to the case with the two screws supplied with the case plus an extra two M3.5 × 6mm screws.

Secure D1 and Q1 to the case with a screw, nut and silicone insulating washer. No insulating bushes are necessary as the packaging of D1 and Q1 has insulation between the mounting screw hole and metal face.

The arrangement for this is shown in the inset in Fig.10. After mounting D1 and Q1, check that the metal tabs of the devices are isolated from the case by measuring the resistance with a multimeter. The meter should show a very high resistance measurement



Here's a close-up of the mounting for the IGBT (Q1) with its insulation washer underneath. Diode D1 is similarly mounted. The cambric insulation at top right covers the 0.01Ω resistor

between the case and any of the diode and IGBT leads.

The complete wiring diagram is shown in Fig.10. The earthing details of the case are most important since the IGBT, D1 and the potentiometers, VR1 and VR2 are all at 230VAC mains potential, yet are attached to the case. If the insulating washers or the insulation of a potentiometer were to break down, the case would be live (ie, at 230VAC) if it was not properly earthed. For the same reason, the **case lid must also be independently earthed**.

The bridge rectifier (BR1) is secured to the case with an M4 screw and nut. It does not require an insulating washer between its body and the case.

Cut the potentiometer shafts to length to suit the knobs. Then install the potentiometers. These are mounted with up to two washers between the pot and the lid for the locating spigot to fit neatly into its locating hole. Fit knobs to the shafts. The central pointer on each knob may require prising out and relocating to the correct orientation.

All mains wiring must be done using 10A 250VAC rated wire. Wiring for the potentiometer must also be mains rated, but it does not need to be 10A rated. The IEC connector must be wired using the correct wire colours (brown for live, blue for neutral and green/yellow striped wire for earth). Use quick connectors for the mains wiring connection to the PCB connectors. Wires to the IEC connector need to be insulated with heatshrink tubing covering all exposed metal terminals for the live and neutral wiring.

For earthing, solder two earth wires from the IEC connector. Each wire should loop through the hole in the earth terminal and be wrapped back on itself so the wire is essentially captured before soldering to the terminal.

Make sure the earth terminal is heated sufficiently with the soldering iron so the solder wets and adheres properly to both terminal and wire. One end of the earth wire is crimped to the earth eyelet and the other to the GPO earth terminal and the earth eyelet on the lid. It is important to use one continuous earth wire length with just the insulation stripped back in the middle to terminate into the GPO earth screw terminal.

The earth eyelets are secured with M4 screws, a star washer and nut, with

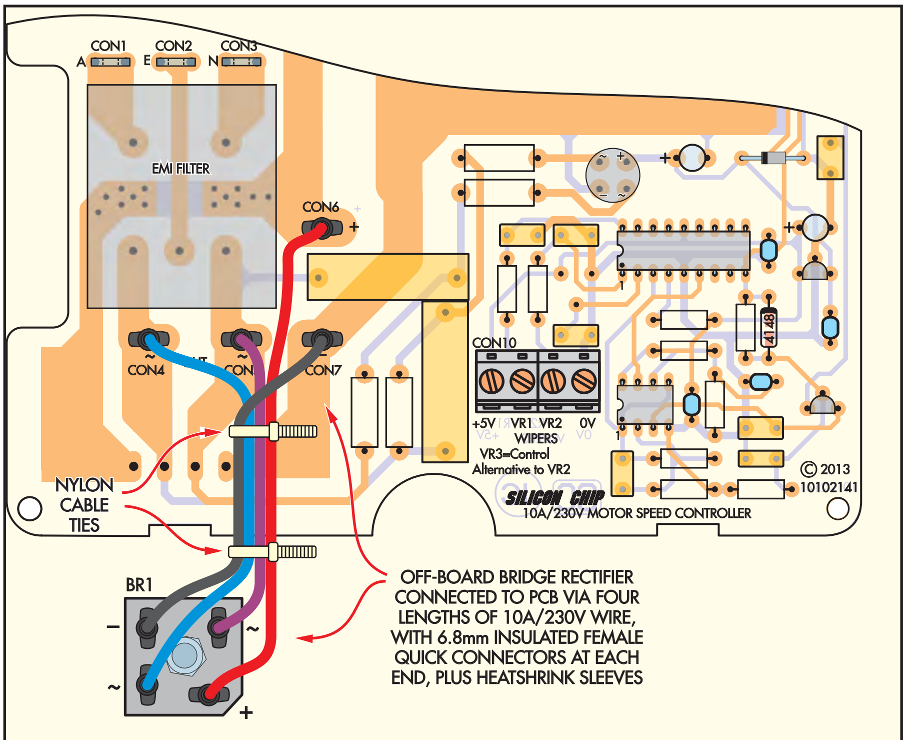
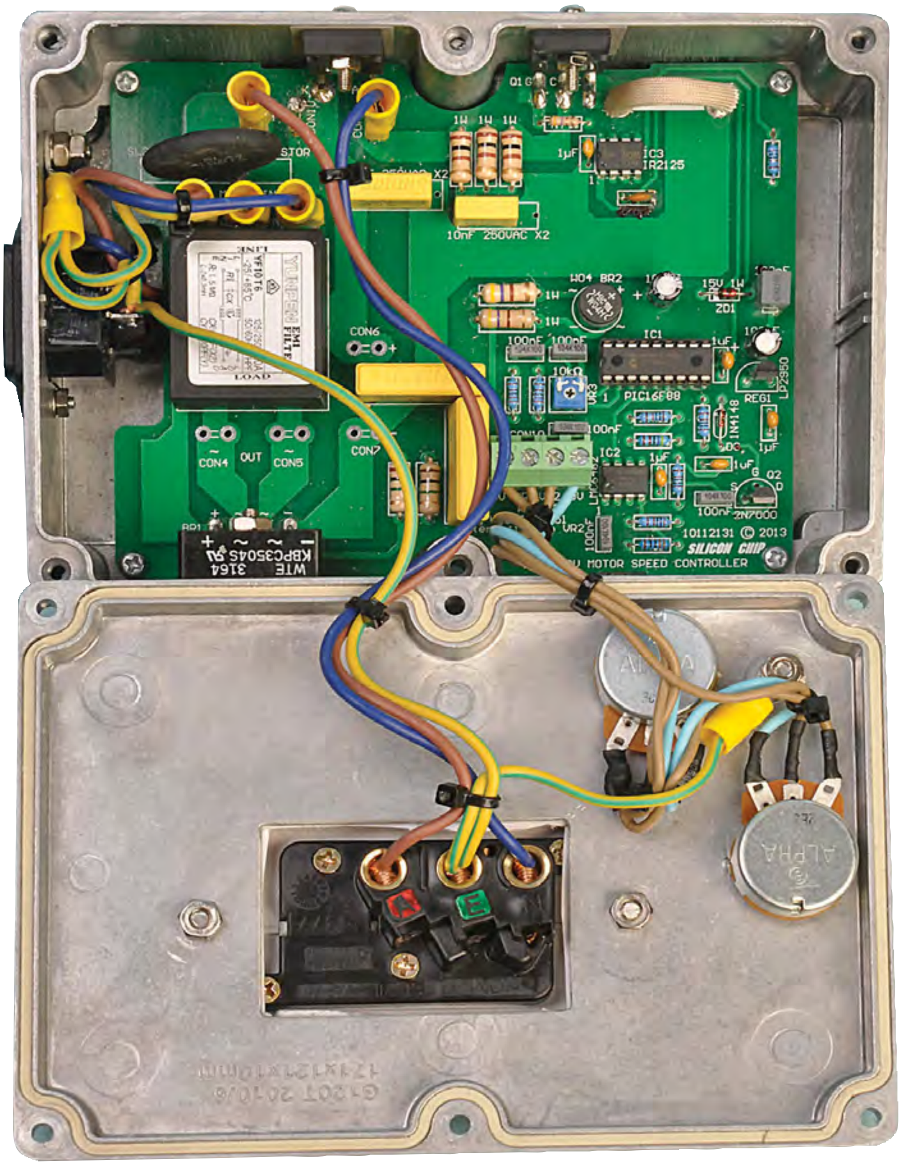


Fig. 11: if your bridge rectifier (BR1) is designed for off-the-PCB mounting, here's how to wire it. You'll need to make up some short spade-lug leads.



The view inside the completed project. Note that there is no power lead connected to the IEC socket in this picture – the case should *never* be open with power applied!

a second nut used as a locknut. Note that a countersunk screw is used on the lid. The IEC connector is secured with the M3 × 10mm countersunk screws, star washers and nuts. Similarly, the GPO is secured with M4 screws, star washers and nuts.

Wire up the potentiometer, again using 250VAC-rated wire. The reason for this voltage rating is to ensure that there is no insulation breakdown to case. Finally, hold the wiring in place using cable ties as shown. This minimises the possibility of any wire breaking loose and making contact with the case.

Testing

Before you power up the circuit, check all of your wiring very carefully against the overlay and wiring diagram. Also **check that the case and lid are connected to the earth pin of the power socket**.

If you are satisfied that all is correct, you are almost ready to screw the lid onto the case. Set VR1 and VR2 fully anticlockwise. If you are not using VR2, set VR3 anticlockwise instead.

When screwing the lid on, note that the case is supplied with a rubber seal that goes around a channel in the lid.

Do not be tempted to operate the speed controller without the lid in place and screwed in position.

Any delving into the circuitry when power is connected is potentially lethal. Preferably, use an earth leakage circuit breaker (safety switch) on the mains supply. If there isn't one already installed in your fuse box, use an in-line type.

The easiest way to test the circuit operation is to connect a load such as a standard (ie, non-speed-controlled) electric drill. Apply power and check that you can vary the drill speed with VR1. Some motors may require adjustment of VR2 for best speed regulation. If using VR3 instead this must be done on a trial-and-error basis with the power off. Disconnect power to the controller by unplugging the IEC mains power lead from the mains wall outlet, adjust VR3 very slightly and replace the lid.

In practice, if VR2 or VR3 is adjusted too far clockwise, the motor may tend to be overcompensated when loaded

Capacitor Codes

Value	µF value	IEC code	EIA code
470nF	0.47µF	470n	474
100nF	0.1µF	100n	104
15nF	.015µF	15n	153
10nF	.01µF	10n	103
1nF	.001µF	1n0	102
470pF	NA	470p	471

All 'X2' class will have printed values

Resistor Colour Codes

	No.	Value	4-Band Code(1%)	5-Band Code (1%)
☐	3	1MΩ	brown black green brown	brown black black yellow brown
☐	3	10kΩ	brown black orange brown	brown black black red brown
☐	1	4.7kΩ	yellow violet red brown	yellow violet black brown brown
☐	2	2.2kΩ	red red red brown	red red black brown brown
☐	1	1kΩ	brown black red brown	brown black black brown brown
☐	2	470Ω	yellow violet brown brown	yellow violet black black brown
☐	1	330Ω	orange orange brown brown	orange orange black black brown
☐	3	100Ω	brown black brown brown	brown black black black brown
☐	1	10Ω	brown black black brown	brown black black gold brown
☐	1	4.7Ω	yellow violet black gold (5%)	n/a

The end of the diecast case must be drilled and filed to house the fused IEC mains input socket, along with a countersunk 4mm hole for the main earth bolt (see diagram below).

and will actually speed up. It may even hunt back and forth between a fast and slow speed. If this happens, readjust VR2 or VR3 anticlockwise for best results.

If you are using a drill at fairly low speed, the motor should not slow down by much as you put a reasonable load on it.

Note that the feedback feature where the idle current can be dialled out will prevent the motor speed from increasing with increasing feedback control adjustment. The idle current can be dialled out by running the motor at the desired speed and then rotating VR2 anticlockwise so that the controller measures the idle current.

Then readjust VR2 clockwise to its required position for best control. The motor speed is then only controlled for current that exceeds the idle current. This feature cannot be easily activated using VR3.

This speed controller must NOT be used with appliances that already have a continuously variable speed controller built into the trigger.

You **can** use the speed controller with electric drills that have two-speed gearbox switching (ie, non-electronic) speed control.

One final point; if you are using this controller with a high power tool such as a large circular saw or 2HP router, it will not give the same kick when starting. That is because of the soft start – the motor will take slightly longer to come up to full speed. This is due to both the NTC thermistor and PWM soft start by the micro.

Troubleshooting

If the speed controller does not work when you apply power, it's time to do some troubleshooting. First, a reminder: all of the circuitry is at 230VAC mains potential and can be lethal. This includes any exposed metal parts on components except those that are tied to the earthed chassis of the case. Do not touch any part of the circuit when it is plugged into a mains outlet. Always remove the plug from the mains outlet before touching or working on any part of the circuit. Before going any further, check the fuse, then give your PCB another thorough check (using a magnifying glass). Check for incorrectly placed components and for component orientation. Also check solder joints.

Fortunately, there is a safe way to check most of the circuit and that is to operate it from a low voltage (12-14V with at least a 20mA current capability) DC supply.

Remember that most plugpacks supply significantly above their rated

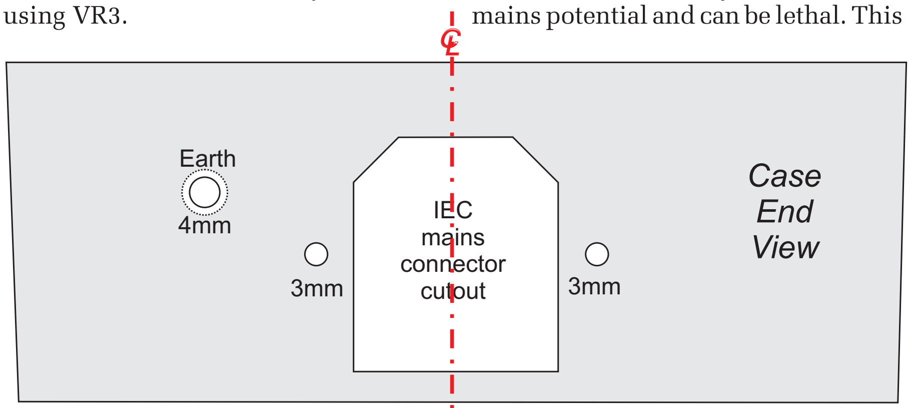


Fig12: drilling detail for the end of the case shown above. Photocopy this and stick it to the end of the case, then drill right through it.

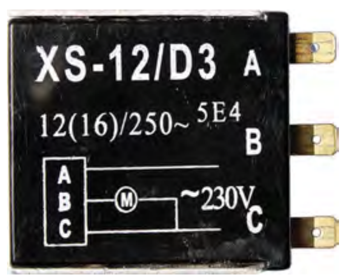
Tools with 'soft start' circuits

When testing the 230V 10A Brush Motor Speed Controller on a 220-240VAC 6.5A Makita LS1017L Sliding Compound Saw, the motor would not operate at all. A quick search on the 'net revealed that this saw includes a soft start circuit to prevent the otherwise massive surge current at start up.

Presumably, the soft start circuit requires an AC supply in order to work. The full-wave rectified DC voltage from the *Motor Speed Controller* prevents it working.

The accompanying photograph shows the soft start module. This is located just inside the end cap of the motor where it receives cooling air drawn in through the motor fan.

The C terminal connects to mains live via the trigger on switch for the saw. The A terminal connects to mains neutral. The soft start connection is between terminals A and B. By disconnecting the soft start A and B terminals then bridging the spade lugs which originally connected to them, we were able to use the *Motor Speed Controller* with this saw.



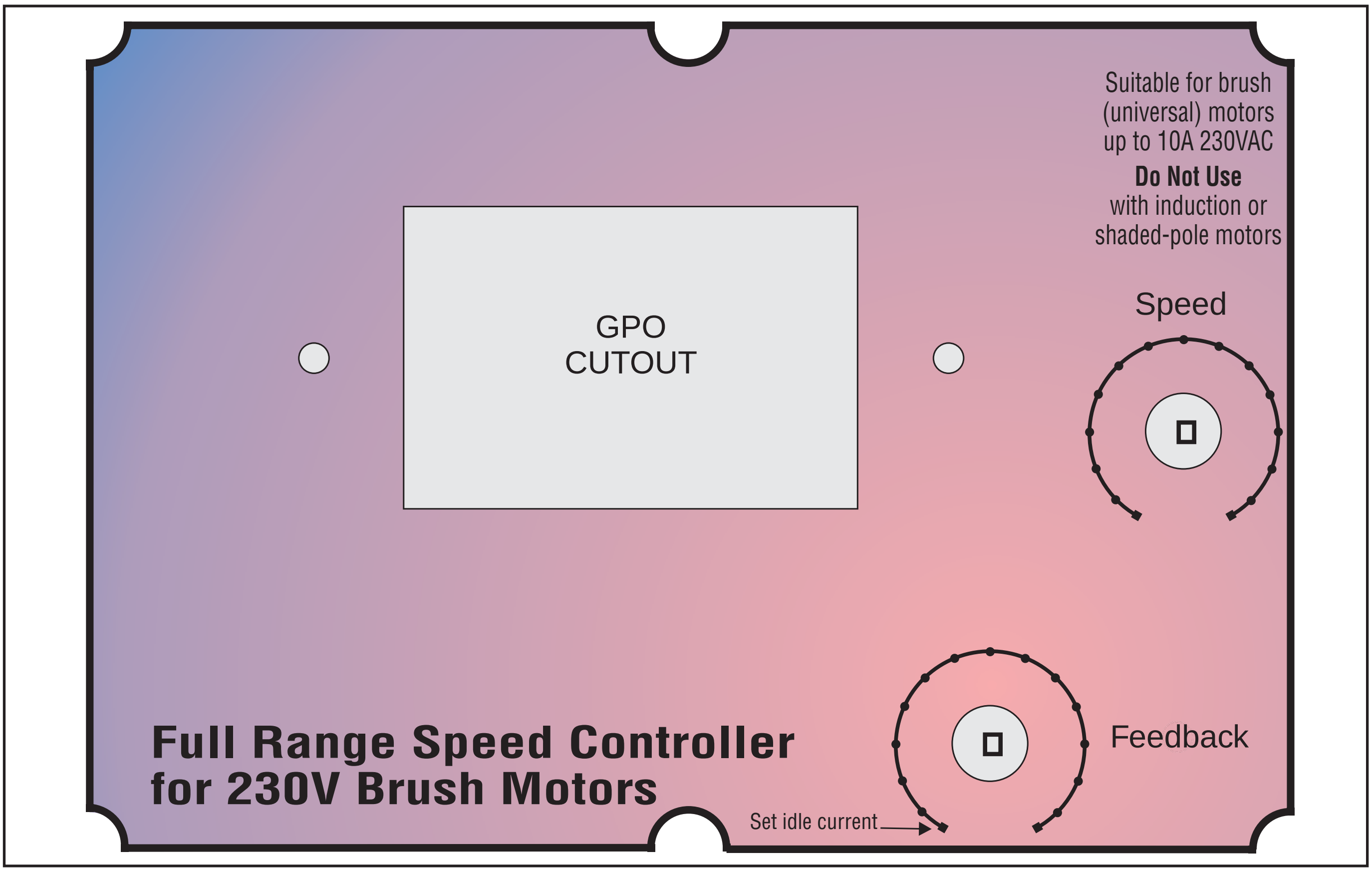


Fig.13: this same-size front panel label can also be used as a drilling/cutting template, as well as the final label – if you want it in colour, it can be downloaded from the *EPE* website and printed on a colour printer. The 4mm countersunk hole for the lid earth screw is not shown – it can go anywhere it doesn't interfere with controls. When applied, the label hides its location.

voltage when unloaded, so we would always err on the lower side, ie, 12V rather than 14V.

You must have the 230VAC mains disconnected from the controller by unplugging the IEC mains lead from the controller and the mains socket.

The supply is connected to Zener diode ZD1 with the positive connecting to the cathode (striped end) and the negative connecting to the anode. Before you connect the supply, measure it to make sure it is not exceeding 14V, otherwise you may damage the 15V Zener diode.

A multimeter can be used to test voltages with the negative lead to the negative supply (anode of ZD1). First, check that there is supply at both pin 1 and 8 of IC3, This voltage should be the same as your power supply connection.

Pin 14 of IC1 should be about 5V (4.85 to 5.15V) as should pin 8 of IC2. Voltage on the wipers of VR1 and VR2 should be adjustable from 0V to 5V when rotating the potentiometer to its full extremes. Pin 6 of IC2b should be 3.4V.

Pin 9 of IC1 should be adjustable from 0V to 5V as VR1 is adjusted over its full range. This is a DC measurement of the PWM signal. Pin 7 of IC3 should range from 0V through to the power supply voltage with VR1 adjustment. A similar voltage range will be available on the gate of Q1. If the gate voltage remains at 0V, then suspect a damaged IGBT or a short from gate to ground.

If your meter can read frequency, the PWM signal at pin 9 of IC1 should give a reading of 980Hz when VR1 is around mid setting. You will not get a frequency measurement with VR1 set at either extreme end of its rotation.

Measuring the resistance between IGBT pins is a simple way to check this component. If there is a short circuit between collector and emitter, or if the gate is shorted to the emitter, then the IGBT is likely faulty unless there is a short on the PCB instead.

Diode (D1) operation can be checked using the diode test on your multimeter – there should not be a short circuit between anode and cathode.

Be sure to remove the power supply connection and replace the lid before reconnecting to the mains.

If the live circuit must be worked on, it must be operated via a 1:1 mains isolation transformer and have an earth leakage circuit breaker (safety switch) installed.

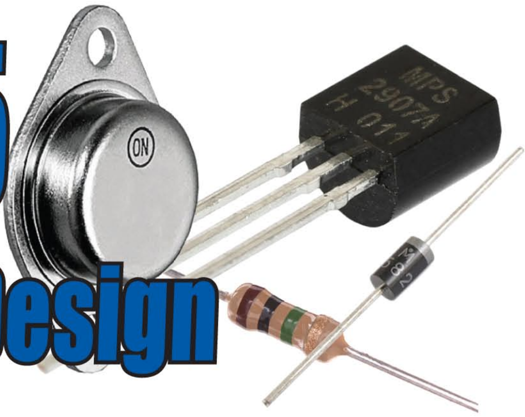
Incidentally, do not try to monitor waveforms with an oscilloscope when powered from the mains unless you know exactly what you are doing. (Even then, you must use a scope with true differential inputs or mains isolation transformer.)

And a final warning!

The entire circuit of this motor speed controller floats at 230VAC. It is potentially lethal. Do not build it unless you know exactly what you are doing. Do not touch any part of the circuit while power is applied from the mains and do not operate the circuit outside its earthed metal case or with its lid off.

This circuit is not suitable for induction motors or shaded pole motors such as those used in fans.

Teach-In 2015



Discrete Linear Circuit Design

Part 3 : Increasing the output

by Mike and Richard Tooley

Welcome to *Teach-In 2015* – this series is aimed at anyone wishing to develop a detailed understanding of linear discrete semiconductor devices and how they are used in a diverse range of circuits. We hope you will join us on this exciting voyage of discovery.

Each part of our *Teach-In* series is devoted to a different aspect of discrete linear circuit design, such as modelling and simulation, measurement and testing, noise and distortion. In last month's instalment, the *Discover* section introduced some powerful virtual measuring instruments that will generate and display test signals. *Knowledge Base* explained hybrid parameters, showing you how they can be used to predict the performance of a transistor amplifier. Our practical feature – *Get Real* – described the various tests and measurements that we carried out on the simple pre-amplifier, including voltage, gain, phase shift and frequency response. We also showed how our prototype performed in relation to the original design objective and how the simulated performance (using SPICE-based software) closely agreed with the performance that we measured using low-cost virtual instruments.

Introduction

In this month's *Get Real* we examine the design and construction of a simple headphone amplifier that can be used to boost the output of MP3 players or similar portable devices. *Discover* introduces you to emitter followers and complementary output stages, while *Knowledge Base* explains the classes of operation used for linear amplifiers. Our *Special Feature* will show you how decibels (dB) are used to specify a wide variety of parameters in electronics, including gain and sound pressure level (SPL).

Knowledge Base: Classes of operation

In last month's *Teach-In 2015*, we introduced some basic transistor amplifier stages designed for linear (Class A) operation. This month, we take a closer look at how an amplifier is categorised by the class in which it is operated and how this affects its performance in terms of linearity, efficiency and distortion.

As explained in Part 1 (*EPE*, February 2015) amplifiers are usually designed to be operated with a particular value of bias supplied to the active devices – for example, the transistor. For linear operation, the active device(s) must be operated in the linear part of their transfer characteristic (V_{out} plotted against V_{in}) as shown in Fig.3.1(a). This form of operation is known as Class A and the bias point is usually adjusted to the mid-point of the linear part of the transfer characteristic in order to permit the maximum

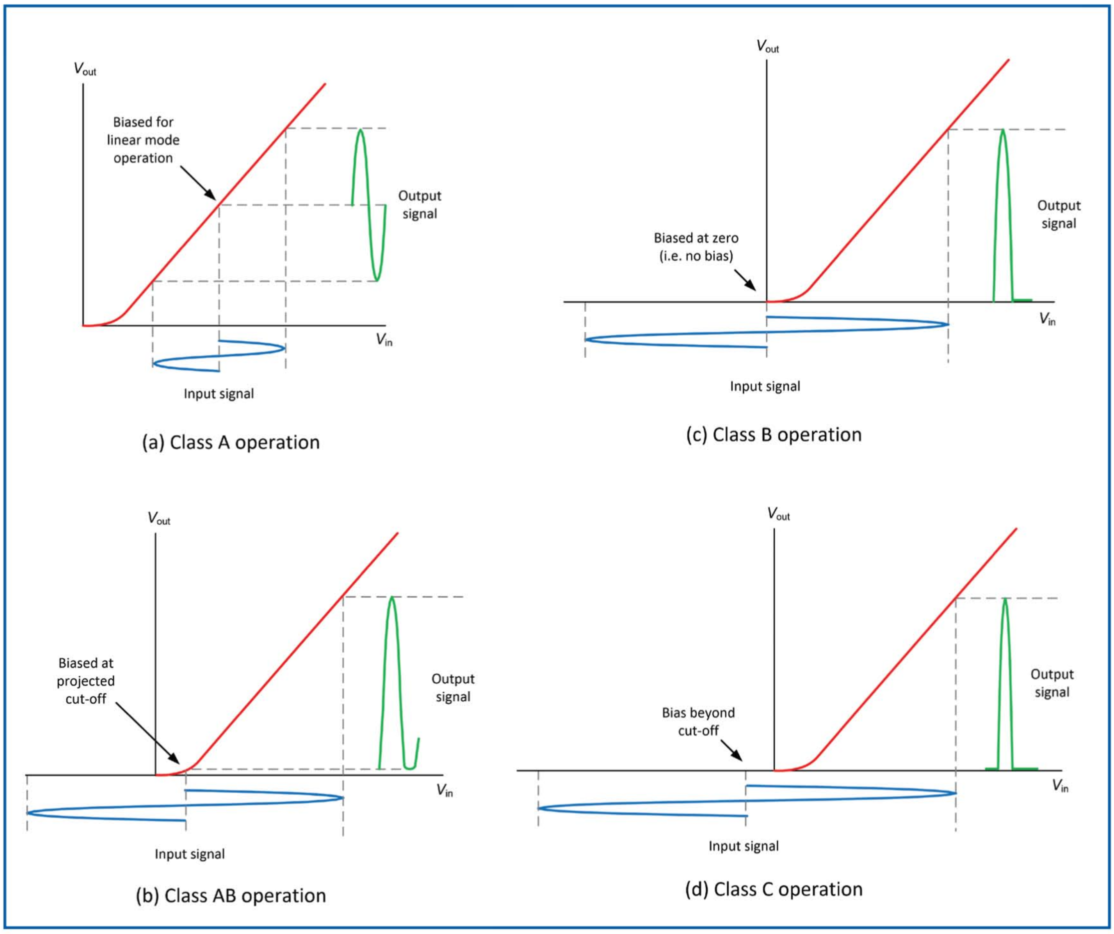


Fig.3.1 Classes of operation

Table 3.1 Classes of operation for linear and quasi-linear amplifiers

Class of operation	Bias point	Conduction angle (typical)	Efficiency (typical)	Application
A	Mid-point (approx.)	360°	5% to 20%	Linear audio amps
AB	Projected cut-off	210°	20% to 40%	Push-pull audio amps
B	At cut-off	180°	40% to 70%	High-efficiency push-pull audio amplifiers
C	Beyond cut-off	120°	70% to 90%	Radio frequency power amplifiers

possible undistorted output voltage swing. Raising the bias point to the middle of the transfer characteristic also helps to avoid any non-linearity of the characteristic that occurs close to the zero-axis crossing point. It is important to note (especially for issues of efficiency) that current will flow in the active devices used in a Class A amplifier during a full cycle of the signal waveform; at no time does the current fall to zero.

Fig.3.1(b) shows the effect of moving the bias point down the transfer characteristic and, at the same time, increasing the amplitude of the input signal. From this, you should notice that the negative-going part of the output signal has become noticeably distorted. This effect arises from the non-linearity of the transfer characteristic that occurs near the origin (the zero point). Despite the obvious non-linearity in the output waveform, the active device(s) will conduct a small amount of current during a full cycle of the signal waveform. This mode of operation is known as 'Class AB', and it provides reasonable efficiency when used in a practical 'push-pull' amplifier stage where two active devices in the output stage operate on alternate half-cycles of the waveform.

Now let's consider what will happen if no bias is applied to the amplifier, as depicted in Fig.3.1(c). The output signal will only comprise a series of positive going half-cycles and the active device(s) will only be conducting during half-cycles of the waveform (ie, they will only be operating half of the time). This mode of operation is known as 'Class B' and it is commonly used in high-efficiency push-pull power amplifiers.

The input and output waveforms for 'Class C' operation are shown in Fig.3.1(d). Here the bias point is set at beyond the cut-off (zero) point and a very large input signal is applied. The output waveform will then comprise a series of quite sharp positive-going pulses. These pulses of current or voltage can be applied to a tuned circuit load in order to recreate a sinusoidal signal. In effect, the pulses will excite the tuned circuit and its inherent flywheel action will produce a sinusoidal output waveform. This mode of operation is only used in RF power amplifiers that are required to operate at very high levels of efficiency. Table 3.1 summarises the classes of operation used in amplifiers.

Finally, it is worth mentioning that there are several other classes of operation in which the active devices are operated under saturated switching conditions rather than in a linear (or quasi-linear) mode. These classes of operation are used in very high power amplifiers that make use of digital switching techniques rather than conventional analogue circuitry.

Fig.3.2 shows a circuit that can be used to demonstrate the operation of an emitter follower in Class A, AB, and B. The model can be entered directly in TINA (see *EPE*, February 2015) or it can be downloaded from the *EPE* website at: **www.epemag.com**. It is worth simultaneously observing the input and output waveforms (using TINA's dual channel virtual oscilloscope) when each mode is selected. The waveforms displayed in Fig.3.2 show the result of operating the circuit in Class B (notice how only positive going half-cycles of the signal appear at the output).

Why is efficiency important?

There are two very good reasons why the efficiency of a power amplifier should be as high as possible. The first relates to the drain on the power supply (often a battery) and the other relates to the amount of heat that a power amplifier produces. In the case of power drain it is important to remember that, even when no signal is present, a Class A or AB, amplifier will be consuming current from its supply. For example, an amplifier with an efficiency of 20% might deliver 1W into a load but at the same time it will consume 5W from its supply. The difference (4W) will be dissipated as heat. Furthermore, this 4W will also be consumed when no output is produced. The continuous heat dissipation may, in turn, result in an unacceptable temperature rise and this might need to be addressed with the use of a substantial heat-sink or other cooling arrangement.

Where the equipment is to be used in a wide range of different ambient temperatures, additional thermal compensation and/or protection might be required. Consideration might also need to be given to ventilation and air-flow. Where equipment is to be operated from batteries, efficiency becomes vitally important in order to ensure acceptable battery life. Because of this, Class B operation is frequently used in portable items of analogue electronic equipment with Class A or AB where a mains or external DC supply is available.

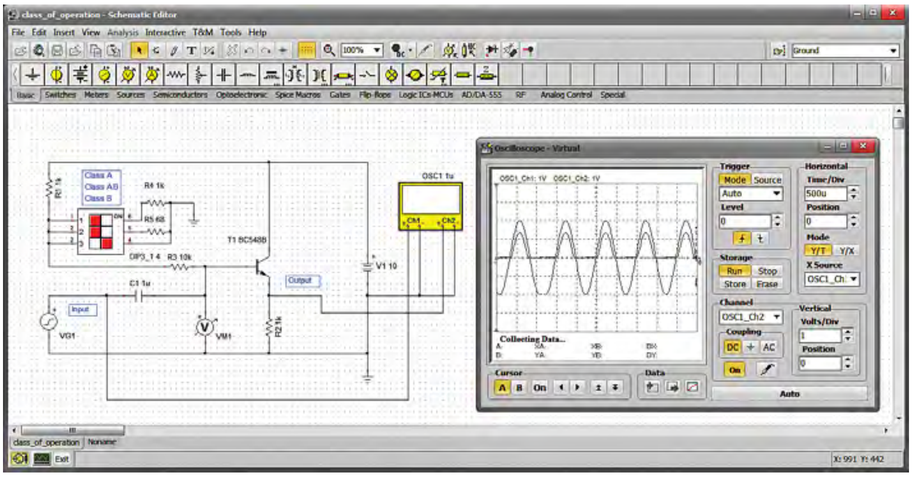


Fig.3.2 TINA model demonstrating operation in Class A, AB and B modes

Discover: Output stages

Power amplifiers

The term 'power amplifier' can be applied to any amplifier that is designed to deliver an appreciable level of power. There are several important considerations for amplifiers of this type, including the ability to deliver current (as well as voltage) to a load, and also the need to operate with a reasonable degree of efficiency (recall that conventional Class A amplifiers are inefficient).

The need for current gain

The simple amplifier stages that we met in the first two instalments of *Teach-In 2015* provided a moderate amount of voltage gain but, in the case of a power amplifier, we also need to have a significant amount of current gain. To help put this into context, consider an audio amplifier that is to be designed for use with a loudspeaker having a nominal impedance of 8Ω. To deliver a modest 1W of power to this load we would need to supply a current of around 350mA at a voltage of 2.8V (both RMS values). The circuits that we have met thus far could be easily adapted to produce a voltage of this magnitude, but the current that they can supply falls far short of the amount that we need. The reason for this is simply that the output impedance of the amplifier stage is significantly higher than that of the load to which they are connected and this, in turn, imposes a limitation on the amount of current that can be delivered

Table 3.2 Data for three commonly available complementary BJT pairs

NPN	PNP	Typical common-emitter current gain (h_{FE})	Maximum collector current (I_C)	Maximum collector power dissipation	Package style
BC550	BC560	250	100mA	500mW	TO92
BD139	BD140	120	1.5A	12.5W	TO126
MJE15032	MJE15033	110	8A	50W	TO220

to it. Fortunately, there is a solution to this problem in the form of the emitter follower that we've already made use of in the output stage of our simple pre-amplifier stage.

Emitter followers

In order to deliver sufficient current to the load, power amplifiers must have a very low value of output impedance. Thus the final stage (or output stage) is usually based on a device operating in emitter-follower configuration. In order to operate at a reasonable level of efficiency, the output stage must operate in Class AB or Class B mode (see *Knowledge Base*). One means of satisfying both of these requirements is with the use of a symmetrical output stage based on complementary NPN and PNP devices.

Complementary output stages

Transistors, whether bipolar junction devices (BJT) or field-effect types, are available in two basic varieties depending upon the polarity of the semiconductor material used in their construction. Conventional BJTs, for example, are available using either NPN or PNP construction. Operation is basically the same for both types of device, with only the polarity of voltage and current reversed. Manufacturers supply a range of devices with very similar (if not identical) characteristics as complementary NPN and PNP pairs. For some applications, these pairs can also be closely matched in terms of current gain and leakage current but, for most purposes, 'off the shelf' devices can be obtained with a reasonable degree of confidence that the characteristics are matched within about ±5% or so. Table 3.2 summarises the data for three commonly available complementary pairs of devices.

Complementary devices are frequently used to realise the output stage of a power amplifier where each of the paired devices operates as an emitter follower to provide current (rather than voltage) gain. A simple complementary output stage is shown in Fig.3.3. TR1 is a suitably rated NPN device, while TR2 is an identically rated PNP device. Both TR1 and TR2 operate as emitter followers, with the output taken from the two emitters, coupled via C2 to the load. In order to bias TR1 and TR2 into Class AB mode, two silicon diodes (D1 and D2) are used to provide a constant voltage drop of approximately 1.2V between the two bases. This voltage drop is required between the bases of TR1 and TR2 in order to bring them to conduction. Since D1 and D2 are both in forward conduction (with current supplied via R1 and R2) they have little effect on the input signal (apart from shifting the DC level).

Fig.3.4 shows an improvement of the basic complementary output stage with the addition of a driver stage (TR1) and a means of adjusting the bias (operating point) of the two output transistors. VR1 is typically adjusted in order to produce an output stage collector current of between 15mA and 50mA (required for Class AB operation) with no signal applied. With VR1 set to minimum resistance, the output stage will operate in Class B (this will produce significantly more cross-over distortion because the two devices may both be cut-off for a brief period of each cycle). Fig.3.5 shows how negative feedback bias (via R2) can be added in order to stabilise the output stage and compensate for variations in transistor parameters.

A practical power amplifier (with some representative component values) is shown in Fig.3.6. This circuit is capable of delivering outputs of up to about 0.5W at reasonable quality to a loudspeaker of 8Ω. A second variable resistor (VR2) has been added in order to adjust the bias for TR1. VR2 is adjusted in order to produce a voltage at the emitters of TR2 and TR3 of exactly half the supply. With TR2 and TR3 sharing the supply voltage equally

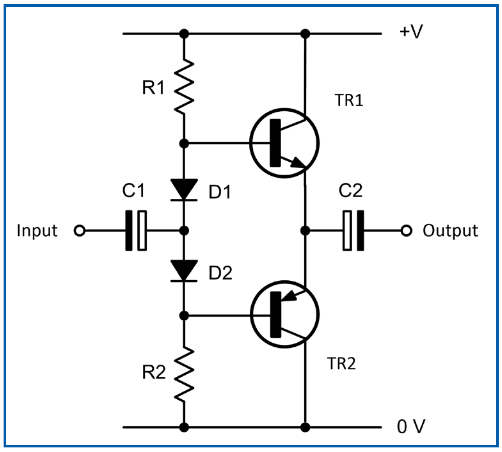


Fig.3.3 Simple complementary output stage

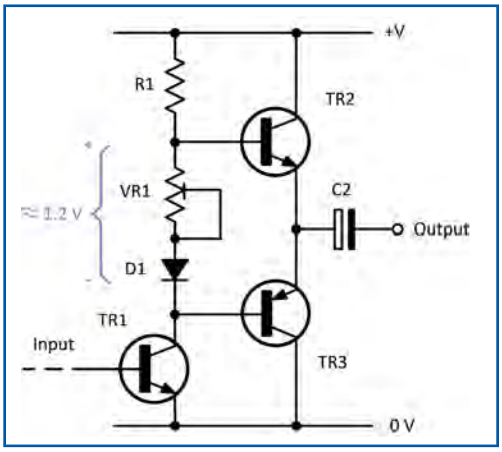


Fig.3.4 A driver stage (TR1) is used to feed the complementary output stage formed by TR2 and TR3

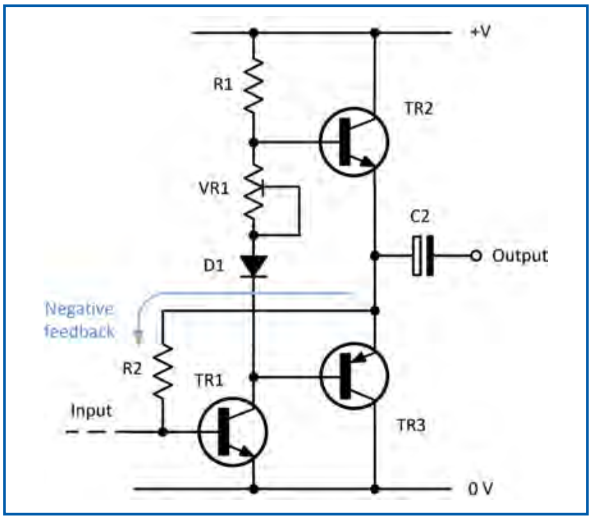


Fig.3.5 A complementary amplifier with negative-feedback-derived bias

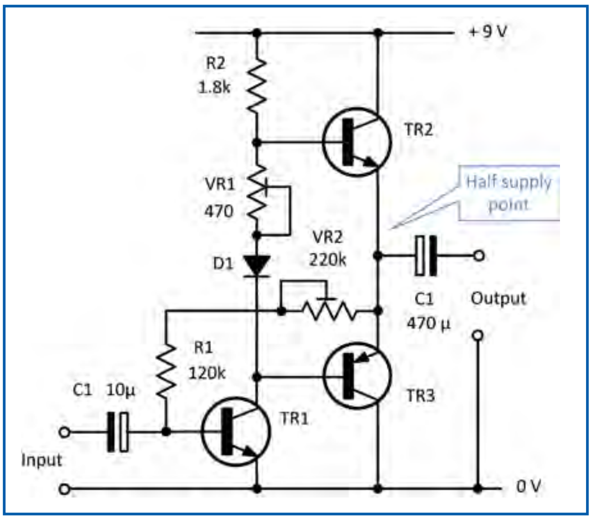


Fig.3.6 A practical amplifier for low power (less than 0.5W output) applications

Special Feature: Understanding decibels (dB)

Decibels (dB) are a convenient means of expressing gain (amplification) and loss (attenuation) in electronic circuits. In this respect, they are used as a relative measure – comparing one voltage with another, one current with another, or one power with another. In conjunction with other units, decibels are sometimes also used as an absolute measure. Hence dBV are decibels relative to 1V, dBm are decibels relative to 1mW, and so on.

Gain

The decibel is one-tenth of a bel which, in turn, is defined as the logarithm, to the base 10, of the ratio of output power (P_{out}) to input power (P_{in}). We have already seen that gain (and loss) may be expressed in terms of power, voltage and current such that:

$$A_p = \frac{P_{out}}{P_{in}} \quad A_v = \frac{V_{out}}{V_{in}} \quad \text{and} \quad A_i = \frac{I_{out}}{I_{in}}$$

where A_p, A_v or A_i is the power, voltage or current gain (or loss) expressed as a ratio, P_{in} and P_{out} are the input and output powers, V_{in} and V_{out} are the input and output voltages, and I_{in} and I_{out} are the input and output currents. Note, however, that the powers, voltages or currents should be expressed in the same units/multiples (eg, P_{in} and P_{out} should both be expressed in W, mW, µW or nW).

It is often more convenient to express gains in decibels (rather than as a simple ratio) using the following relationships:

$$A_p = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right) \quad A_v = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)$$

$$\text{and} \quad A_i = 20\log_{10}\left(\frac{I_{out}}{I_{in}}\right)$$

Attenuation

Note that a positive result will be obtained whenever P_{out}, V_{out}, or I_{out} is greater than P_{in}, V_{out}, or I_{out}, respectively. A negative result will be obtained whenever P_{out}, V_{out}, or I_{out} is less than P_{in}, V_{in} or I_{in}. A negative result denotes attenuation rather than amplification. A negative gain is thus equivalent to an attenuation (or loss). If desired, the formulae may be adapted to produce a positive result for attenuation simply by inverting the ratios, as shown below:

$$A_p = 10\log_{10}\left(\frac{P_{in}}{P_{out}}\right) \quad A_v = 20\log_{10}\left(\frac{V_{in}}{V_{out}}\right)$$

$$\text{and} \quad A_i = 20\log_{10}\left(\frac{I_{in}}{I_{out}}\right)$$

where A_p, A_v or A_i is the power, voltage or current gain (or loss) expressed in decibels, P_{in} and P_{out} are the input and output powers, V_{in} and V_{out} are the input and output voltages, and I_{in} and I_{out} are the input and output currents. Note, again, that the powers, voltages or currents should be expressed in the same units/multiples (eg, P_{in} and P_{out} should both be expressed in W, mW, µW or nW).

It is worth noting that, for identical decibel values, the values of voltage and current gain (or loss) can be found by taking the square root of the corresponding value of power gain. As an example, a voltage gain of 20dB results from a voltage ratio of 10 while a power gain of 20dB corresponds to a power ratio of 100 (ie, 10 times 10).

Finally, it is essential to note that the formulae for voltage and current gain are only meaningful when the input and output impedances (or resistances) are identical. Voltage and current gains expressed in decibels are thus only valid for matched (constant impedance) systems. Table 3.3 gives some useful decibel values but, to help put this into perspective, here are a few examples:

Example 1

An amplifier with matched input and output resistances provides an output voltage of 1V for an input of 25mV. Express the voltage gain of the amplifier in decibels. The voltage gain can be determined from the formula:

$A_v = 20 \log_{10}(V_{out}/V_{in})$

where $V_{in} = 25\text{mV}$

and $V_{out} = 1\text{ V}$

thus: $A_v = 20 \log_{10}(1\text{V}/25\text{mV})$

$= 20 \log_{10}(40)$

$= 20 \times 1.6 = 32\text{dB}$

Example 2

A matched 600Ω attenuator produces an output of 1mV when an input of 20mV is applied. Determine the attenuation in decibels. The attenuation can be determined by applying the formula:

$A_v = 20 \log_{10}(V_{out}/V_{in})$

where $V_{in} = 20\text{mV}$

and $V_{out} = 1\text{mV}$

thus:

$A_v = 20 \log_{10}(20\text{mV}/1\text{mV})$

$= 20 \log_{10}(20) = 20 \times 1.3$

$= 26\text{dB}$ (loss)

Example 3

An amplifier provides a power gain of 33dB. What output power will be produced if an input of 2mW is applied? Here we must re-arrange the formula to make P_{out} the subject, as follows:

$A_p = 10 \log_{10}(P_{out}/P_{in})$

thus: $A_p/10 = \log_{10}(P_{out}/P_{in})$

or $\text{antilog}_{10}(A_p/10) = P_{out}/P_{in}$

Hence

$P_{out} = P_{in} \times \text{antilog}_{10}(A_p/10)$

Now

$P_{in} = 2\text{mW} = 20 \times 10^{-3}\text{W}$ and $A_v = 33$ dB, thus:

$P_{out} = 2 \times 10^{-3}\ \text{antilog}_{10}(33/10)$

$= 2 \times 10^{-3} \times \text{antilog}_{10}(3.3)$

$= 2 \times 10^{-3} \times 1.995 \times 10^{3} = 3.99\text{W}$

Example 4

A 600Ω driver produces an output power of +16dBm. Express this in watts and determine the equivalent output voltage.

The output power (expressed in mW) can be determined by applying the formula:

$P_{out} = 10 \times \text{antilog}_{10}(16)$

$= 39.8\text{mW} = 0.0398\text{W}$

The RMS voltage (assuming a sine wave) can be determined from:

$V_{out} = \sqrt{(P_{out} \times R_{out})} = \sqrt{(0.0398 \times 600)}$

$= 4.89\text{V}$

Table 3.3 Decibel equivalents of power, voltage and current ratios

Decibels (dB)	Power ratio	Voltage ratio	Current ratio
0	1	1	1
1	1.26	1.12	1.12
2	1.58	1.26	1.26
3	2	1.41	1.41
4	2.51	1.58	1.58
5	3.16	1.78	1.78
6	3.98	2	2
7	5.01	2.24	2.24
8	6.31	2.51	2.51
9	7.94	2.82	2.82
10	10	3.16	3.16
13	19.95	3.98	3.98
16	39.81	6.31	6.31
20	100	10	10
30	1,000	31.62	31.62
40	10,000	100	100
50	100,000	316.23	316.23
60	1,000,000	1000	1000
70	10,000,000	3162.3	3162.3

Sound pressure level (SPL)

Decibels also provide us with a very convenient way of expressing sound pressure levels in relation to a standard reference level (usually the threshold of hearing). The human ear has a logarithmic response to sound pressure and using a logarithmic ratio helps make the numbers smaller and easier to deal with.

Sound pressure level is defined as: $SPL = 20\log_{10}(p_{rms}/p_{ref})$

where p_{rms} is the RMS value of sound pressure (measured in a unit called the pascal, Pa) and p_{ref} is the reference pressure (usually 20μPa) which represents the average threshold of hearing (ie, the smallest noise that can be perceived by the human ear). Some representative sound levels (expressed in dB relative to an SPL of 20μPa) are shown in Table 3.4.

It should be noted that the values shown in Table 3.4 are given for illustrative purposes only and, in practice they are subject to a typical variation of around ±10dB. **Sound levels of 130dB are at the threshold of pain for most people and prolonged exposure to sound at these levels is likely to result in irreversible damage and subsequent hearing loss**. Finally, it is important to remember that sound pressure varies with distance from the source so it is important to specify the distance when we make meaningful sound level measurements.

Table 3.4 Representative sound levels expressed in decibels

Level (relative to 20μPa)	Typical
0dB	Threshold of hearing
10dB	Quiet bedroom at night
20dB	Rustling leaves
30dB	Quiet urban area at night
40dB	Library
50dB	Quiet urban area during the day
60dB	Normal conversation
70dB	Radio or TV audio; motor car at 70 mph
80dB	Average factory; diesel lorry at 20 feet
90dB	Machinery; motor mower at 10 feet
100dB	Large motorcycle; farm tractor
110dB	Power saw; printing press
120dB	Jet engine at 100 feet
130dB	Jet engine at take off
140dB	Peak of music output from a rock band

it is possible to obtain the maximum undistorted output voltage swing. Later in *Teach-In 2015* we will be introducing more complex power amplifier circuits that are able to provide substantially more output than this simple arrangement.

Get Real: A simple headphone amp

Our second *Get Real* project is designed to satisfy the need for a simple means of boosting the output of an MP3 player, mobile phone, tablet, or similar portable device when used with high-quality headphones. We will need an amplifier offering good linearity, coupled with a modest amount of voltage gain capable of driving a relatively low impedance load and with a frequency response that extends over the full audio range, from around 20Hz to well over 20kHz.

Before we get started, and at the commencement of any design project, it is important to be aware of the characteristics and limitations of any device that will be used at the input or output of the circuit that we are designing. In this particular case we need to start with the properties of the headphones before attempting to prepare an outline specification for the amplifier that we will be using to drive them. We also need to be aware of the signal that we will be using to drive the amplifier which, in this case, will be the output of an MP3 or similar portable audio player.

Table 3.5 Sound levels typically produced by 40Ω headphones with sensitivity of 105dB/mW

Input power	Sound power level (ref: 1mW at 1cm)	Required signal voltage (pk-pk)
10μW	85dB	60mV
100μW	95dB	180mV
1mW	105dB	570mV
10mW	115dB	1.79V
100mW	125dB	5.66V

Most MP3 players (and similar portable devices) can happily drive the earphones or headphones that they are supplied with up to reasonable volume. Such headphones usually have an impedance up to around 100Ω, with 40Ω being typical and these are driven with voltages of up to about 2V RMS. Professional and high-quality headphones for the more discerning audiophile often have a significantly higher impedance (eg, 300Ω or 600Ω) and, because of this, they will not generally produce sufficient sound output. This limitation can be overcome with the aid of an external headphone amplifier like the one that we will be describing in this article. Headphone sensitivity is clearly rather important and so it's worth taking a careful look at this parameter and the effect that it might have on the amount of signal that we need to produce for a particular level of sound.

Sensitivity

Headphone sensitivity is usually expressed in terms of the sound pressure level produced at a specified distance from the driver (often 10mm) when a power of 1mW is applied to the headphones from a 1kHz sinusoidal source. The sound pressure level is in dB/mW (decibels per milliwatt) and ranges from about 95dB/mW to around 110dB/mW.

It's worth taking an example to help put this into context. Let's assume that you have a typical set of headphones rated at 105dB/mW with an impedance of 40Ω. Table 3.5 shows the sound pressure levels produced by the headphones and the signal levels that would be needed to generate them. Notice how an increase of around 100 times signal voltage is required to produce an increase of 20dB in SPL and that several volts of signal will be required to generate a loud sound.

In recent years there has been a move by several of the high-end manufacturers to abandon the traditional measurement (dB/mW) and instead to quote headphone sensitivity in terms of dB/V. This can be a little confusing because it yields a very different figure in terms of decibels. Unfortunately, to find the equivalent sensitivity in terms of db/mW requires a knowledge of the impedance of the headphones. A couple of examples might help to make this clear.

Converting sensitivity: dB/mW to dB/V

As an example, consider the low-cost Koss KSC75 ear-clip headphones. These unit are rated for an SPL of 101dB/mW. Since the impedance of the headphones is 60Ω the voltage required to produce an output of 101dB SPL would be given by:

$$V = \sqrt{(P \times R)} = \sqrt{(10^{-3} \times 60)} = \sqrt{(0.06)} = 0.245\text{V}$$

The increase (expressed in dB) from 0.245V to a reference level of 1V is:

$$A_v = 20\log_{10}(1/0.245) = 20 \times 0.611 = 12.22\text{dB}$$

SPL for 1V is thus (101 + 12.22) = 113dB.

Converting sensitivity: dB/mW to dB/V

The AKG Y50 headphones on the other hand are rated at 115dB/V. These headphones have a rated impedance of 32Ω and so the power required to produce an SPL of 115dB will be given by:

$$P = V^2 / R = 1^2 / 32 = 0.031\text{ W} = 31\text{mW}.$$

The difference (expressed in dB) from 31mW to a reference level of 1mW is:

$$A_p = 10\log_{10}(1/31) = 10\log_{10}(0.0323) = 10 \times (-1.49) = -14.9\text{dB}$$

SPL for 1mW is thus (115 – 14.9) = 101.1dB

Maximum SPL and dynamic range

A very wide dynamic range is essential for faithful reproduction of music. This can run from a note which is just audible to the loudest crescendo. Hence, it can be informative to ascertain just how much

Table 3.6 Representative headphone specifications

Headphone type	Sensitivity (dB/mW)	Impedance (nom. at 1kHz)	Frequency response (note 2)	Driver diam (mm)	Max rated power
Sony V55	104dB	40Ω	6Hz to 25kHz	40	1W
Pioneer SE-MJ721	104dB	40Ω	6Hz to 28kHz	40	
Pioneer HDJ-1500	108dB	32Ω	5Hz to 30kHz	50	3.5W
Sennheiser HD7-DJ	115dB (note 1)	95Ω	8Hz to 30kHz		
Koss KSC75	101dB	60Ω	15Hz to 25kHz		
Audio-Technica ATH-ANC7b	109dB	300Ω	10Hz to 25kHz	40	500mW
Audio-Technica ATH-MSR7	100dB	35Ω	5Hz to 40kHz	45	2W
AKG Y50	115dB (note 1)	32Ω	16Hz to 24kHz	40	100mW

Notes
1. Sensitivity expressed in dB SPL when driven with a signal of 1V RMS at 1kHz
2. These figures are often quoted by manufacturers without specified reference levels so they should only be taken as a rough guide to the headphone performance. Wherever possible, it is best to refer to a frequency response graph like that shown in Fig.3.7.

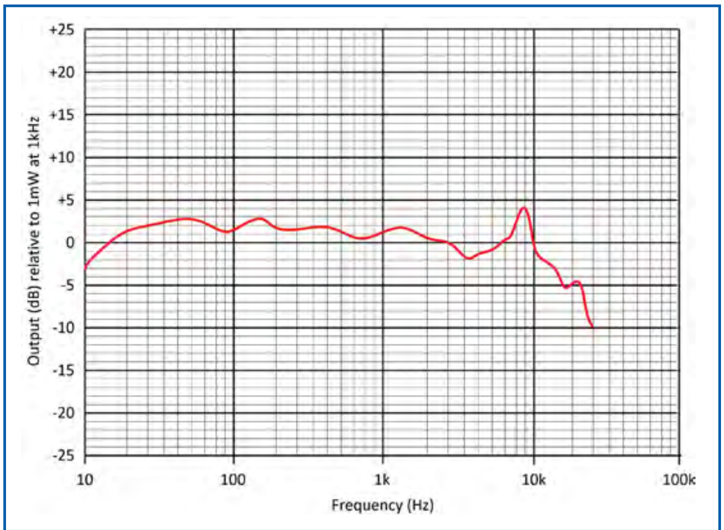


Fig.3.7 Typical headphone frequency response

SPL a particular pair of headphones can produce. Taking the AKG Y50 model as an example, these produce an SPL of just over 101dB for 1mW, so we can infer that they will produce around 20dB more output with the maximum rated power of 100mW applied. This is equivalent to an SPL of 121dB. If you look back at Table 3.4 you will see that this represents the sound level created by an idling jet engine!

The Sony V55 units produce a rated SPL of 104dB and a maximum power of 1W. This suggests that these units can reproduce a sound level of over 130dB, equivalent to the sound produced by the same engine when producing maximum thrust! However, what they don't tell you is that the distortion produced by headphones (as well as amplifiers and loudspeakers generally) is liable to increase rapidly beyond a certain output level and, for this reason, although the sound that's produced might appear to be deafeningly loud it might also be rather distorted. This is an important point that we will be returning to in a future instalment of *Teach-In 2015*.

Now let's look at the specifications for headphones that we might want to use in conjunction with our headphone amplifier. Table 3.6 shows a representative selection of headphones, ranging in price from under £20 to over £200. The typical frequency response for a mid-range set of headphones is shown in Fig.3.7 (note the fall-off below 20Hz and above 10kHz).

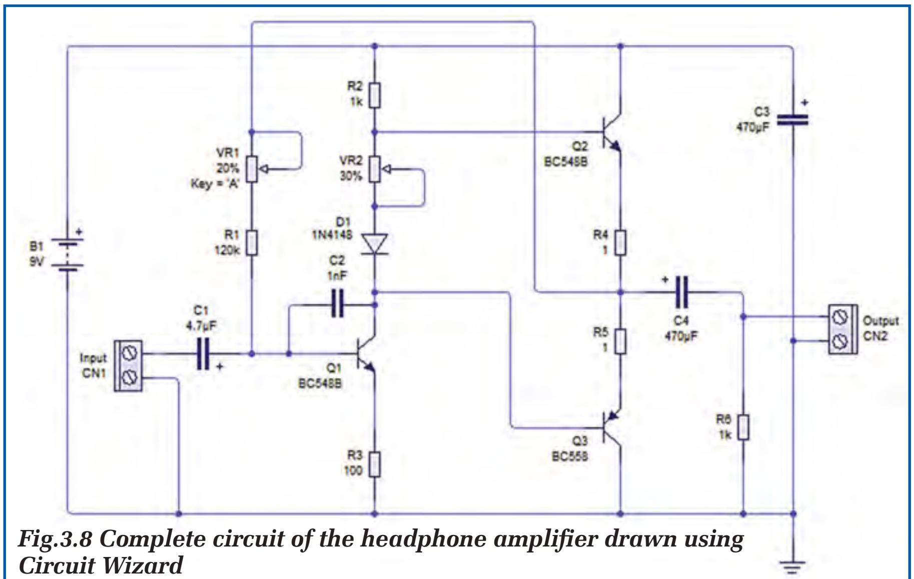


Fig.3.8 Complete circuit of the headphone amplifier drawn using Circuit Wizard

Circuit description

The complete circuit diagram of the headphone amplifier is shown in Fig.3.8. The circuit uses three transistors. The first stage, Q1 and associated components, operates in common-emitter mode and provides a voltage gain of approximately 10 (ample for this particular application). This stage is followed by a complementary emitter-follower pair (Q2, Q3) and associated components. Base bias for the first stage, Q1, is derived from the output of the second stage and the feedback configuration helps to stabilise the DC operating conditions (see *Discover*).

Coupling

The input signal is coupled into the pre-amplifier by means of C1 and output signal is coupled to the load by means of C4. These two capacitors provide DC isolation for the headphone amplifier so that the DC bias current and voltages for Q1, Q2 and Q3 are unaffected by whatevers DC conditions are present at the input and output. In most cases it is expected that, as far as DC levels are concerned, the input and output will be at ground potential (but this may not always be the case). If this is not the case then it may become necessary to uprate the working voltage and/or polarity of the relevant coupling capacitors. Within the headphone amplifier, the signal is directly coupled from Q1 to Q2 and Q3. The lower frequency cut-off is determined mainly by the values of C1 and C4, while the upper frequency cut-off is determined by the value of C2 (using shunt voltage negative feedback). The voltage gain may be increased by reducing the value of R3 (without affecting the bias conditions) but a voltage gain of 10 should be more than adequate for use with most MP3 and other portable audio players, and an external volume control can easily be fitted at the input of the amplifier (see Fig.3.9).

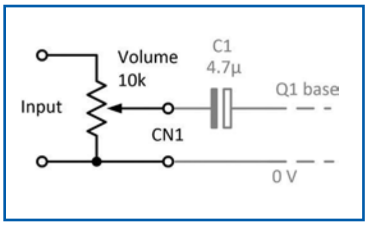


Fig.3.9 Adding a volume control

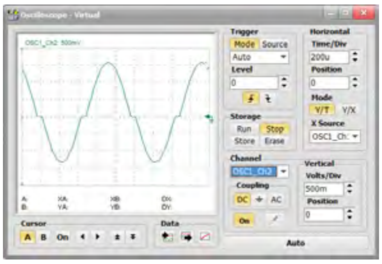


Fig.3.10 Effect of cross-over distortion on output waveform (VR2 can be adjusted to eliminate distortion)

Table 3.7 Outline design specification for headphone amplifier

Voltage gain	10 (approx.)
Frequency response	Better than 10Hz to 20kHz at –3dB
Input impedance	5kΩ (approx)
Output impedance	Less than 4Ω
Max output	50mW into 15Ω at 1kHz with less than 1% THD
Phase shift	180° at 1kHz (ie, output inverted)
Supply voltage	9V (12V max.)
Supply current	Less than 10mA (no signal), 50mA (max output)
Distortion	Better than 0.2% THD at 1mW into 600Ω

Bias adjustment

As already noted, the bias for Q1 is obtained from the output at the junction of R4 and R5. This is often referred to as the 'half-supply point' because the DC supply is effectively shared equally between Q2 and Q3. Current is fed from this point via the bias adjustment pre-set, VR1. This control is adjusted in order to produce a DC voltage of 4.5V at the junction of R4 and R5. The class of operation is adjusted by means of VR2. This sets the voltage that appears between the base of Q2 and Q3 but note that the minimum bias voltage between the two bases (when VR2 is short-circuit) will be approx. 0.6V (defined by the forward voltage of silicon diode, D1).

VR2 is adjusted to produce a small current flowing in the collector of Q2 and Q3. If the bias is set too high, then efficiency will be low and battery life will be reduced. If set too low, efficiency will be high but distortion might be appreciable due to the cross-over effect as Q2 and Q3 move from conducting to non-conducting states. Fig.3.10 shows the effect of distortion at the zero axis crossing point. The easiest way to adjust the output stage current is to connect a DC voltmeter across either R4 or R5. With no signal, a voltage drop of 5mV will correspond to a standing collector current of 5mA. It's worth noting that these two low-value resistors have been included to provide some protection for Q2 and Q3. As the current flowing in R4 and R5 increases, the base bias voltage for Q2 and Q3 will be correspondingly reduced. So, for example, if the emitter current in Q2 or Q3 was to increase to 50mA, the respective base bias voltage would be reduced by 50mV, opposing the original change and helping to bring back the emitter current to a more modest value. We will be looking at this later in the series when we introduce thermal protection for high power amplifiers.

Components

1 PCB, code 906 available from the *EPE PCB Service*, size 52mm × 90mm,
3 PCB mounting 2-way terminal blocks
1 PP3 battery connector
1 PCB mounting miniature jack connector (optional)
1 SPST on/off switch

Resistors (0.25W, 5%)
1 120kΩ (R1)
2 1kΩ (R2, R6)
1 100Ω (R3)
2 1Ω (R4, R5)
1 220kΩ (VR1)
1 220Ω (VR2)

Capacitors
1 4.7µF (C1)
1 1nF (C2)
2 470µF (C3, C4)

Semiconductors
2 BC548B (Q1, Q2) 1 BC558B (Q3)

Choice of transistor

We selected BC548B transistors for use as the NPN stages (Q1 and Q2) and a BC558B for use in the PNP stage (Q3). They are all low-cost devices from the B-gain group (see *Discover* in February 2015, *EPE*). Many other devices may be used in this circuit, but Q2 and Q3 should be reasonably closely matched in terms of current gain (h_{FE}) and collector current rating. As before, it is important to check on the device pin-out before making any substitution.

Construction

Our PCB was designed to be built into a small enclosure or incorporated into a larger enclosure along with other circuitry and it measures just 52mm × 90mm. The PCB component layout and copper track layout was produced using Circuit Wizard (see next month for details) and is shown in Figs. 3.11 and 3.12. The board can be purchased, ready drilled, from the *EPE PCB Service*, code 906. Our finished prototype, ready for testing, is shown in Fig.3.13.

Next month

In next month's *Teach-In*, *Get Real* we will show you how we used our favourite software applications, TINA and Circuit Wizard to design, analyse and construct the headphone amplifier. If you've built your own version of our *Get Real* project you will be able to put what you've learned into practice by following our examples and carrying out your own measurements. To help you with this, *Discover* will introduce you to distortion and distortion measurement. *Knowledge Base* will introduce constant current and constant voltage sources and, for good measure, our *Special Feature* will show you how you can use Circuit Wizard to design your own printed circuit boards.

Fig.3.13 Completed headphone amplifier ready for testing

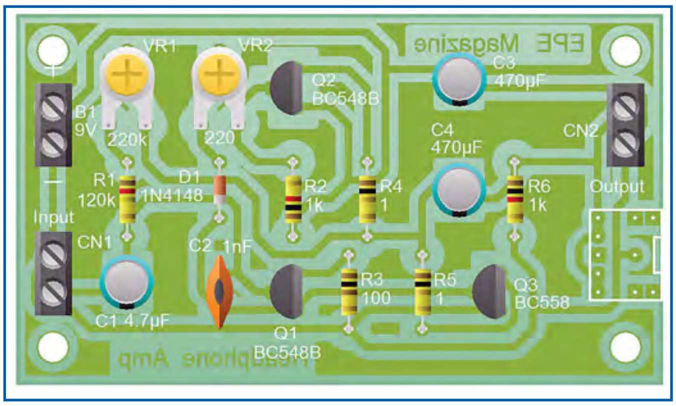


Fig.3.11 PCB component layout

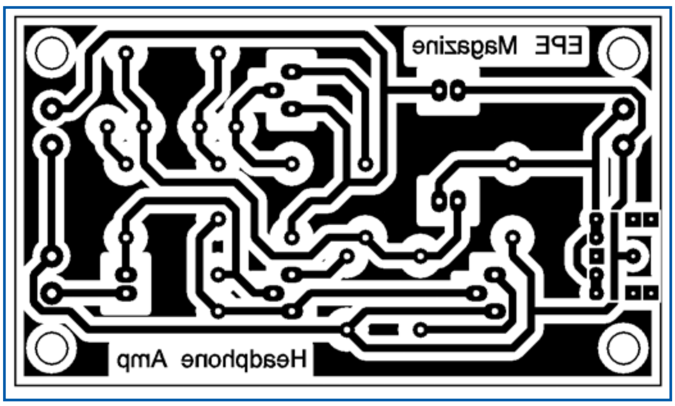


Fig.3.12 PCB track layout

NET WORK

by Alan Winstanley

Hello commander...

IN January's column I considered the Windows options available to anyone thinking of buying or building a new desktop PC. Since then, I spent a week or two assembling a new PC to handle my spiralling Internet-based workload. For an operating system, Windows 7 has been a firm favourite rather than the unloved Windows 8, but Windows 10 (thanks to a numbers game, there will be no version 9) is scheduled to arrive later this year. Free upgrades to W10 for Windows 7 and 8 users are promised, so I rushed to get a copy of Windows 7 Professional while I still could. Microsoft has now withdrawn mainstream support for Windows 7 (see the Windows Lifecycle page at **http://windows.microsoft.com/en-GB/windows/lifecycle**) but don't worry – this popular OS has plenty of life in it yet, and disks are still available from reputable IT vendors such as Scan (**scan.co.uk**).

Building a PC is always a nice satisfying job, and the new machine was soon assembled and purring away under the desk. (The full story is on: **http://bit.ly/netwk0415a**). My first task was to install Avast Anti Virus, after which a blizzard of Windows updates was downloaded automatically from Microsoft's website. With only one exception, a motley bunch of legacy 32-bit Windows programs and hardware was installed successfully on this 64-bit machine. In actual fact, the Windows 7 setup was very slick and commendably smooth. So far, anyway...

During an upgrade like this, software activation codes may be needed and printouts of emails with serial numbers can be very useful. A few programs are tied to a PC and are gone forever if the system gets upgraded, which can add some significant costs. Hardware drivers and software patches can be downloaded directly from the web – but, as usual, beware of phony websites. Unfortunately, while googling for a driver, a careless mouse-click introduced a PUP (Potentially Unwanted Program) into my shiny new system within the blink of an eye. On this occasion, Avast quarantined every attempt to install an unwanted Omiga-Plus Search toolbar, which tried to hijack my web browser, but I still had to deal with some damaged Windows shortcuts afterwards.

After installing the basics, a few little Windows productivity tweaks followed, starting with the indispensable but deprecated Weather, Time and CPU Usage widgets (right-click the desktop and choose 'Gadgets'). I previously mentioned **itsamples.com** as the source of the W7 Network Activity Icon which was installed next, along with two more handy tools from the same site: Notification Area Cleaner deleted some stubborn system tray icons and Caps Unlocker, which works (most of the time) to reset Capslock after a delay.

...Computer reporting

A Windows 7 Startup Sound Changer was fetched from **http://winaero.com/download.php?view.10**, so my preferred startup sound would play ('Hello Commander, Computer Reporting' from Mattel Intellivision's 1981 *Space Spartans* – download from **http://bit.ly/netwk0415b**). The program's Russian designer, Sergey Tkachenko, offers a very wide variety of small free programs and themes for all versions of Windows, and his **winaero.com** website is worth a visit.

Attention then turned to fine-tuning Internet Explorer, which can become onerous and frustrating. It uses Microsoft's Bing as its default search provider, but I found myself switching constantly to Google instead. A range of IE add-ons offers web surfers a choice of search providers, but IE failed to install them using `Tools/ Manage add-ons/ Search Providers/ Find more...` The only way of installing them was to visit the Internet Explorer gallery directly at: **www.iegallery.com**. Toolbars can also be enabled or disabled via the IE add-ons menu. Unwanted toolbars or scanners can sometimes be sideloaded into IE without noticing, including Ask, McAfee or Google, which several websites will try to install unless you untick that option. As a rule, stick to a very small number of proven toolbars to prevent IE being reduced to a crawl. However, an annoying IE pop-up can appear, warning that toolbars are slowing down the system. 'Speed up browsing by disabling add-ons', it advises. This is the only opportunity users have to change the pop-up's timing: in my case the 0.5-second warning stopped IE from loading, so next time you see this pop-up click 'Choose Add-ons' and change 'Tell me when the delay exceeds....' to something greater (eg, 1.5s). In future the toolbar will load without interruption.

The web has become unrecognisable since Internet Explorer arrived twenty years ago, downloadable onto a floppy disk. Unfortunately, there is no substitute for spending time checking IE's myriad settings, including the various View menu items and options available via the Tools menu. It's not surprising that many users opt for a simpler life using Google Chrome or Firefox instead. However, new Windows 10 will include a slicker, lightweight and extensible web browser called 'Spartan', which can be likened more to Google Chrome.

Internet Explorer pops up this warning about slow-loading add-ons. Click 'Choose add-ons' to change it

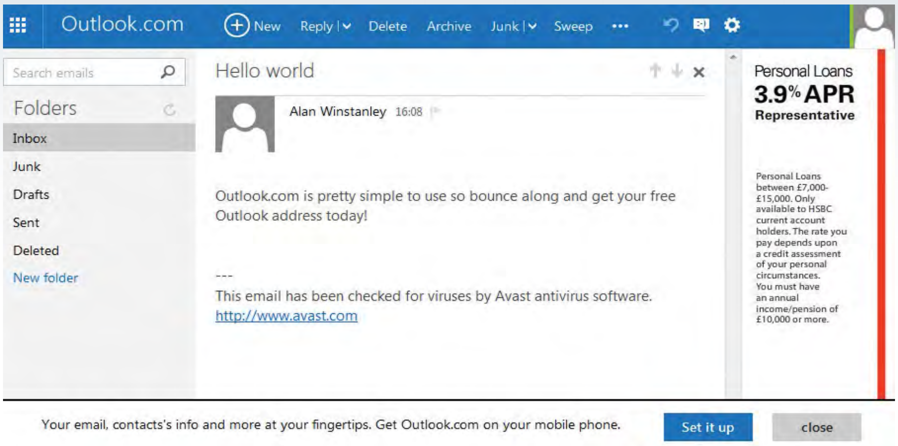
Email choices

Next on the new PC installation came the email setup. Those who manage email using a desktop PC are facing more limited choices, as online services start to dominate everyday services. A fellow *EPE* writer has already ditched PC-based email software altogether and he handles everything online instead. What alternatives are there?

I was delighted that my tried-and-trusted Eudora 7.1 worked perfectly

on a Windows 7 64-bit machine. After copying some folders containing ten years' worth of email onto the new PC, Eudora burst into life and was instantly sending and receiving mail. I enjoy Eudora's multi-threaded POP3 collection that fetches half a dozen mailboxes at once, its humorous UI messages, fast search engine, its templates ('Stationery') and Eudora's powerful filtering and sorting rules. The program is also currently compatible with popular web-based mail services. It does, however, make a hash of forwarding HTML mail, and some recipients will see your mail in Times New Roman regardless of the typeface it was written with, or they may 'Reply' with a blank email for some reason. If this doesn't matter to you (me neither!), Eudora 7.1 is free, fast and dependable and is still available on the web – one route is via the Wayback Machine at **http://bit.ly/netwk0415c**, where a copy of the original Eudora website is hosted.

The heavyweight Microsoft Office offers the ubiquitous Outlook with calendaring and contact management, but this could be overkill for many home applications. There are various options for Office users, most of which are based on a software rental model (check your local site for prices): Microsoft Office 365 Personal Edition is £5.99 a month or £60 a year. It's compatible with Windows 7 or Mac OS X 10.6 or later and has cloud-based functionality built in, so it can be accessed online. Office 365 Home (five user) costs nearly £80 a year: ouch. Microsoft makes it clear that if you cancel your 365 subscription, the software de-activates itself after a grace period and switches to 'read only' until you subscribe again. Microsoft Office Professional 2013 is the traditional PC-based business suite of Word, Excel, PowerPoint, OneNote, Outlook, Publisher and Access for a once-only licence fee. Retail prices for Office Professional 2013 vary wildly, so shop around. It can be downloaded and a serial number is bought separately. Many PC users will be happy with the free Thunderbird email program, from the same stable as Firefox. Thunderbird is easy to use and is probably the best choice for free PC-based email software today. Also check out a free trial of



Outlook.com from Microsoft offers a free web-based mail service that is also compatible with many POP3 email clients

'The Bat' software, which majors on its built-in security, available from **www.ritlabs.com**. Whichever program you use, if things go wrong a visit to **http://mail2web.com** offers a fast way of checking POP3 mail online, especially if you are suffering network problems and need to keep an eye on mail.

For many readers, web-based services will be the modern answer and they can be accessed via a phone, tablet or web browser at home or on the go. A simple, free and long-established webmail service is offered by GMX, which claims 13 million customers across the US and Europe. GMX is now owned by Germany's United Internet AG – the name behind the European host 1&1 and Britain's Fasthosts Ltd. A visit to **gmx.com/gmx.co.uk** offers more details and a free sign-up. The same is true over at **mail.com**, another 1&1 company offering similar free mail.

The main alternatives for consumers are Google's Gmail and Microsoft's equivalent Outlook from **outlook.com**. Both services can now import POP3 email from another hosted service (eg, a domain name's mailbox), as can GMX, so multiple mail addresses can be consolidated into one web-based account. These services might encourage users to move away from the idea of traditional computer-based email software. In my view, Outlook is more user-friendly and reassuring to use than Gmail, whose users face a daunting range of options and privacy questions; so now might be the time for new users to start with an **outlook.com** email address. The toughest problem might be finding a username that hasn't already been taken!

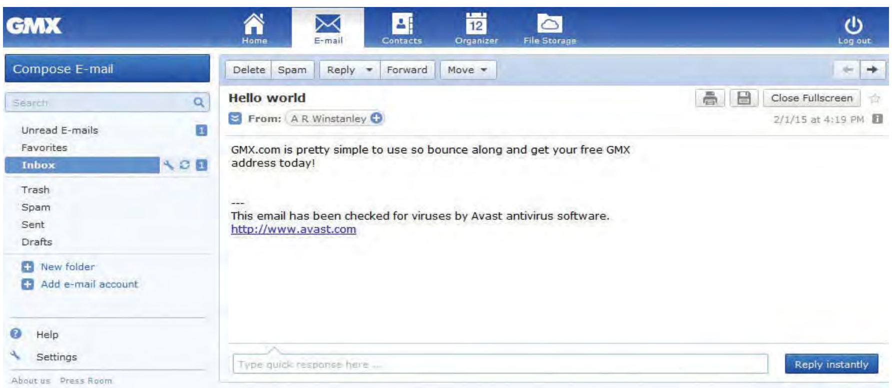
There is no doubt that the technical headaches and constant need to manage email programs, contacts, security, spam and backups on hard disk will gradually become a thing of the past, as more services are moved onto the cloud.

Publish your own paperback on Amazon

In last month's column I suggested a route towards publishing one's own material online. If you have the makings of a book bursting to get out, then marketing an ebook using Amazon's formidable Kindle platform is an excellent way of entering the self-publishing business. Perhaps you have a favourite interest, passion or hobby, or just fancy writing, say, childrens' stories or a novel, in which case I would encourage anyone to dip their toes into the water and start publishing their work this way. Compared with traditional routes, the start-up cost is zero, and even a modest ebook will offer authors hands-on experience of the entire production and payment process from end to end.

Budding authors are not restricted to producing ebooks, though. The advent of web-based print-on-demand (POD) services has made it possible to print and distribute traditional paperback books to individual order. No longer is it necessary to commit to large print runs or wrangle with book publishers or literary agents; self-published POD services offer high quality results in a glued (perfect bound) paperback format that can be virtually indistinguishable from commercial paperbacks.

Amazon's POD book printing is offered by Createspace. In fact, if you start with a paperback book first, Createspace will offer to generate a Kindle version of it automatically. A paperback title is then integrated seamlessly into Amazon's website for international distribution through their global sites. Furthermore, authors can buy copies of their printed books at cost price or drop-ship them (ie, order



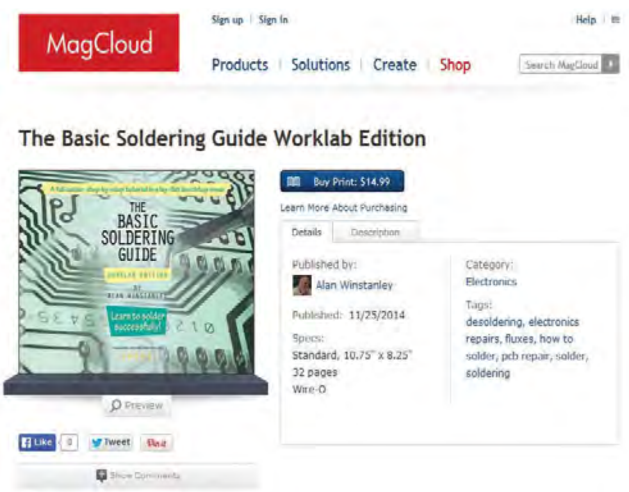
GMX is a free and simple webmail service that can also collect regular POP3 mail

for direct delivery to a recipient) using Createspace's very efficient international distribution.

Createspace will faithfully print the layout, text, images and style of your book exactly as you design it, in full colour if specified. Allowances must be made for gutter margin and other print aspects, but downloadable templates for Microsoft Word make this job very easy. While Createspace is quite forgiving about some aspects, a book cover must be designed separately to a strict specification and some trial and error must be expected before you get it right.

There is little alternative to looking around Createspace's website and getting a feel for what's involved. Check out the FAQs, pricing, royalty options and US tax implications too. After successfully uploading a file and cover image, if it passes Createspace's design criteria, then a proof copy has to be purchased so you can make any final adjustments, after which your book can go on immediate sale with just a mouse-click.

Other self-publishing routes include Magcloud, now part of Blurb. Originally owned by HP, it uses HP Indigo printers to provide POD books and journals to self-publishers, and the high-quality, full-colour print produces very professional results. From experience, the design process is far more rigorous than Createspace and it is aimed more at design professionals who use industry-standard software like Adobe InDesign and Acrobat for PDF creation. Magcloud offers more print options, including spiral Wire-O binding, which made it the ideal choice for the *Basic Soldering Guide Worklab Edition*, a layflat wire-bound book that was professionally designed for education and training institutes.



Magcloud is a high-quality POD self-publishing site that lets professional designers of books, niche magazines and journals print and sell their work internationally

Authors can also drop-ship or buy their own Magcloud books at cost price, with various shipping options provided. Their service is highly efficient. Unlike Amazon, Magcloud leaves it to you to market your book, although it is also made available for sale on Magcloud's website. If you can design professional layouts – or know an Adobe freelancer who can do it for you – Magcloud is an ideal POD source for high quality niche magazines, journals, papers and books.

Some POD services levy a fee per book to process the file and arrange book production and distribution through other channels; Bookbaby charges from $579 per project but offers worldwide distribution through book stores. Another potential POD supplier is LuLu, which dates from 2002 and is one of the earliest suppliers in this market. A number of POD suppliers will offer the option of selling PDF downloads for you as well. With the Internet bringing on-demand printers and authors together this way, it's never been easier to get your work into print.

That's all for this month's *Net Work*. You can contact the writer at: **alan@epemag.demon.co.uk**

- The *Basic Soldering Guide Handbook* (paperback version) is now on sale direct from Wimborne Publishing Ltd – visit the Online Shop via: **www.epemag.com**

PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

A larger display for the LPLC board

I love it when what appears at first to be a problem turns out to be a gem. Such an incident happened a few months back when *EPE* reader Gary Bleads bought an LCD display for his LPLC board, hoping to try out some of the demo code. Unfortunately, the display didn't work as expected. As he said on the magazine's web forum: *'Has anyone tried the "oscilloscope" demo in the October Pic n' Mix. It sort of worked for me, but the oscilloscope only filled 1/4 of the screen, the text was backwards and the trace was red, not blue'.* You can see the conversation thread here: **www.chatzones.co.uk/discus/messages/7/15470.html**

Gary had accidentally purchased a 2.2-inch QVGA LCD module (240 × 320 pixels) rather than the prescribed 1.8-inch 128 × 160 pixel display. An easy mistake, because they look identical. And, by luck, they have very similar display controller ICs.

It looks like a great display, and it costs just 84p more than the smaller display. I had to get one, so I bought two. If you are interested, search eBay for '2.2" Serial SPI TFT LCD Display Module 240 × 320 Chip ILI9340C PCB Adapter SD Card'. It currently costs £3.85, with free postage.

Confusingly, the detailed description of the part states it comes with an ILI9341 driver rather than the ILI9340C mentioned in the description, but fortunately Gary was able to find further details on the Internet, and get the display working with the template code.

The larger display has an extra pin – which is a bit of a surprise – it's a data output pin. This could be very useful, if it actually works – it means we may be able to read data back from the screen. This will make real-time graphics displays faster, possibly. Not all display modules actually connect this signal from the display chip to the edge connect, so we will have to wait and see once we have the board wired up. Having the pin connected and labelled on the edge connector is a positive step though.

The circuit to drive this display is almost identical to that for the smaller display; we add just a single connection to the pin for the serial read line from the display. If you are using the serial peripheral this should be connected to the correct input pin – but since we are bit-bashing the serial interface we can connect it to any I/O pin. The pin is specified by a `#define` in the code, so it is easy to change (as long as you are bit-bashing). The serial peripheral pins are fixed on the IC, so you must wire to the correct pins if using it. We did anyway, in case we decide to move to the hardware peripheral.

The set of commands supported by this display is very similar to that of the smaller display. Gary only needed to update the initialisation sequence function to get it to work, with all the existing 2D and text functions operating as expected.

Gary kindly created a 'driver' for this new display, and we have added those files to the template code, which is available for download from the magazine website.

To manage the source code files, we've taken a simple approach for selecting the type of display being used – you simply remove one and add the other into the list of files in your project. For example, select the 'Project' window, expand the 'Header Files' list,

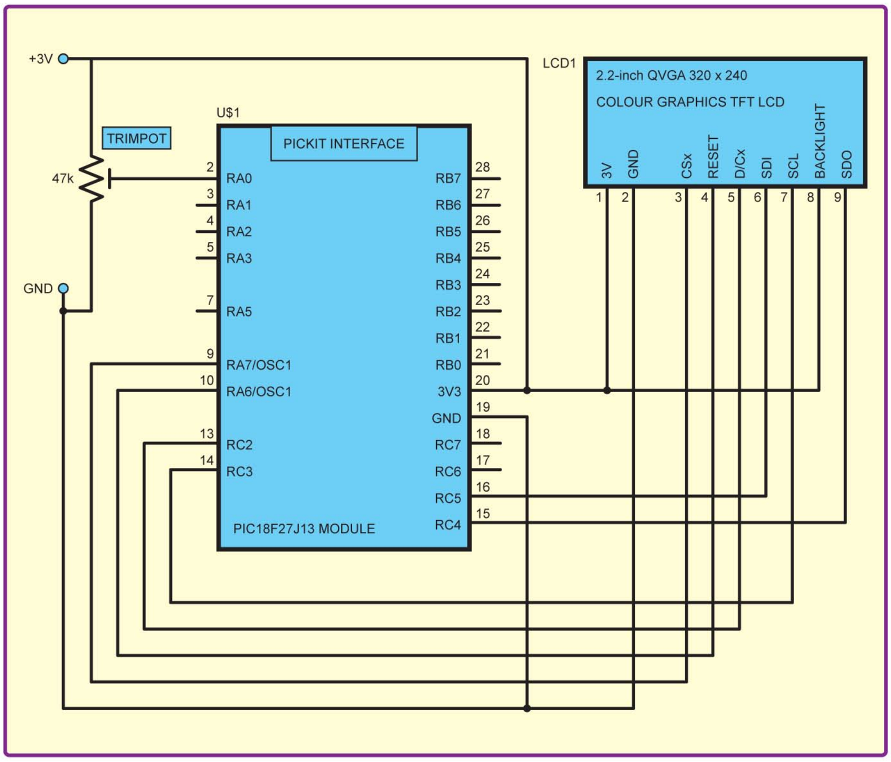


Fig.2. Revised schematic to manage the new display. Note how we added only a single pin, the data out signal

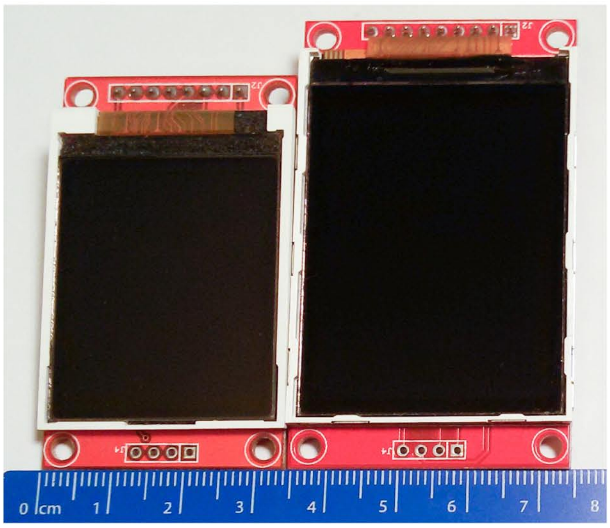


Fig.1. The original 1.8-inch display alongside the new 2.2-inch display; the larger display has almost four-times as many pixels

right click over the old LCD header file and select 'Remove from Project'. This does not delete the file, it just excludes it from the build. You can add the new LCD header file by right clicking over the 'Header Files' heading, and selecting 'Add Existing Item'. When you do this with your own files, remember to copy any new files into the source directory first, so all the files are located in one sub-directory structure. When changing LCD driver files, don't forget to repeat the above steps for the '.c' source file.

```
void LCD_Writ_Bus(unsigned char da)
{
    LCD_SDA=(da & 0x80) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
    LCD_SDA=(da & 0x40) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
    LCD_SDA=(da & 0x20) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
    LCD_SDA=(da & 0x10) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
    LCD_SDA=(da & 0x08) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
    LCD_SDA=(da & 0x04) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
    LCD_SDA=(da & 0x02) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
    LCD_SDA=(da & 0x01) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
}
```

Display update rate

The drawback of a larger display is that, without sophisticated update methods, filling the screen with data can take a long time. Another reader noticed that from power on to a filled display took nine seconds – clearly unacceptable. So why is this? The main reason is that unlike smartphone displays that are connected to their processor by a very high-speed parallel bus, ours connect by a relatively slow, two-wire interface – the SPI bus. When wired on a prototype board such as in our example, the SPI bus clock speed must, unfortunately, be kept low due to the long track traces between the processor and the LCD. These lengthy tracks introduce capacitance that distorts the edges of the data and clock signals, and cross talk between the wires that adds noise to the signals, corrupting data bits or adding rogue clock pulses. When using a properly designed PCB or very short traces it's possible to significantly increase the SPI bus clock speed. The ILI9341 IC can run at up to 10MHz – far faster than our current 'bit-bashed' interface.

The bottleneck in our code is nicely contained within a single function (shown above right).

We will pick up on the optimisation of this routine in the coming months.

GUI?

Such a large display calls out for an attractive graphical user interface, or 'GUI'. Sadly, we have been unable to find any software libraries online that provide a GUI for these small SPI-based display modules. So, if your project needs a GUI then you should choose either a display module supported by Microchip's graphics library, buy a MikroElektronika PIC+ display board or roll your own code. The lack of a GUI is not a major obstacle, however, as GUIs tend to be used on more 'general computing' platforms, and you are more likely to use this in a dedicated application with very specific, fixed displays – such as our oscilloscope example.

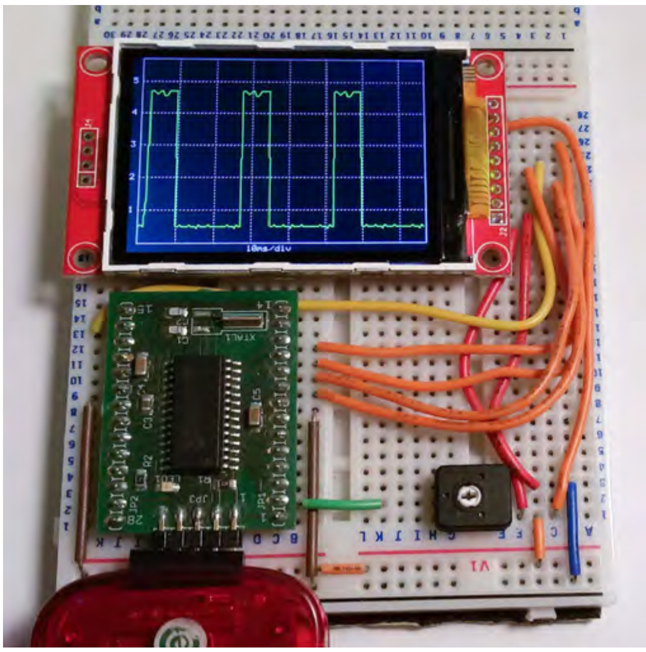


Fig.3. Using the display – the pinout between the two boards is virtually identical, while showing four times as much data. Both feature an SD Media connector on the rear

Next month

In May's issue we'll take a look at the PIC32+Wi-Fi module from ByVac. It's a small development board with a smaller Wi-Fi 'dongle' attachment, at a very reasonable price. The processor is preloaded with the company's own high-speed BASIC-like language, which through a mix of compilation and interpretation results in an apparently easy-to-use yet fast executing language. Intrigued? I'm looking forward to putting it through its paces, and finally creating my first 'Internet of Things' device – a remote workshop environmental monitor. You can take a look at the module here: **www.byvac.com**

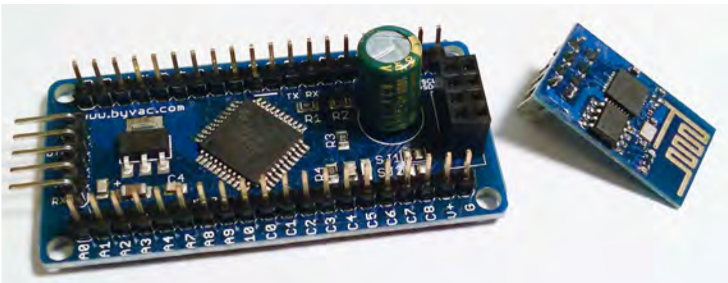


Fig.4. Next month: the ByVac PIC32+Wi-Fi development kit

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at ***@MikeHibbett****, and from his blog at* ***mjhdesigns.com***

RPI16OUT from Zeal Electronics

In this, the third of our trio of reviews of I/O boards from Zeal Electronics, our resident Raspberry Pi expert, Mike Tooley, turns his attention to the RPI16OUT, an optically isolated 16-bit digital output board for the Raspberry Pi. Like the two other boards reviewed in the December 2014 and February 2015 issues, this board was designed by Dr Stephen Alsop for use in 'harsh' and noisy industrial environments.

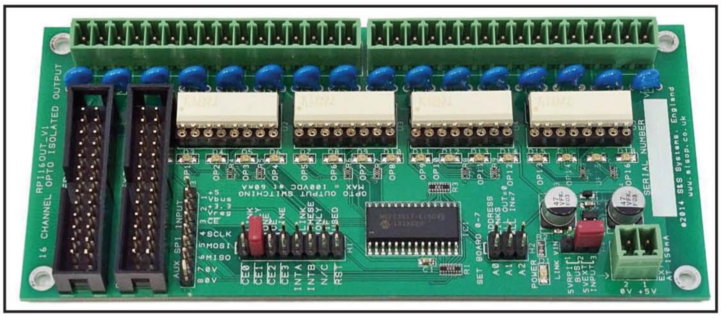


Fig.1. The RPI16OUT 16-bit optically isolated output board for the Raspberry Pi (to facilitate output connection the basic board, as supplied by Zeal electronics, is fitted with the male header part of a two-part 3.5mm spacing industrial connector)

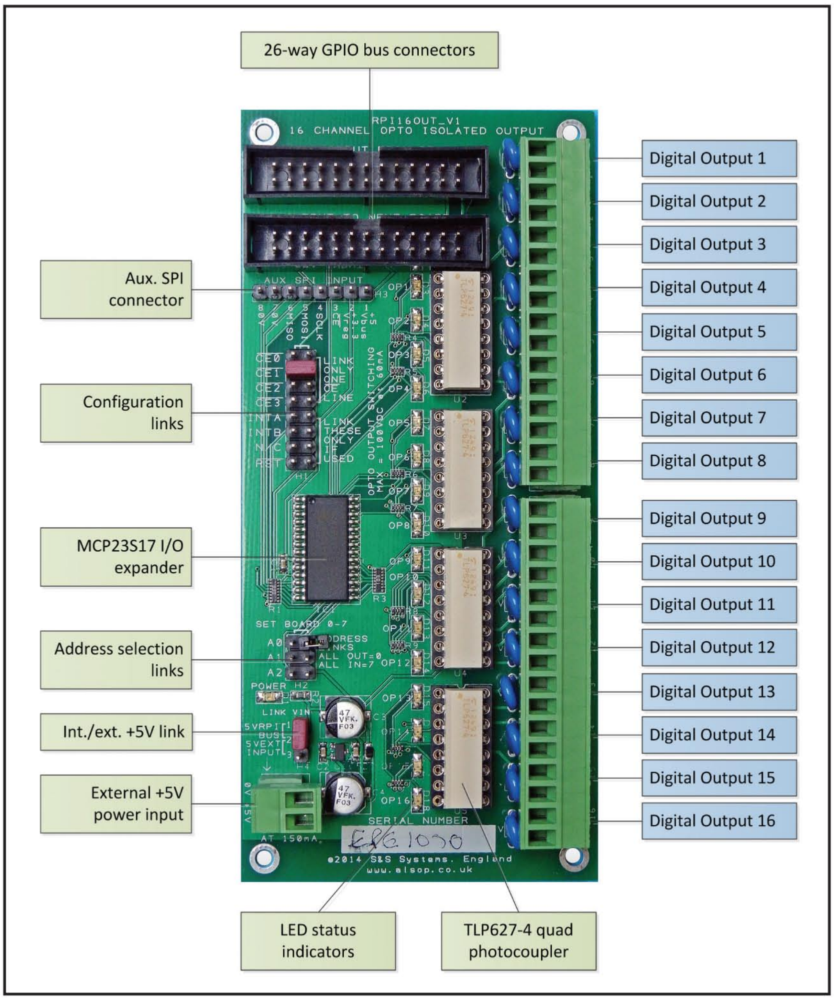


Fig.2. The RPI16OUT board layout

The RPI16OUT is one of three high-performance optically isolated interface boards for the Raspberry Pi from Zeal Electronics Ltd. The optical isolation eliminates the problems that would normally be associated with outputs and inputs that are at different potentials above or below the ground potential of the Raspberry Pi. A high degree of isolation is important in a number of applications, for example when switching high-voltage circuits or triggering power control devices. Without a high degree of output isolation, high potentials and switching transients could damage or disrupt the operation of the Raspberry Pi. With the RPI16OUT board, each of the 16 outputs is individually isolated from the others, thus minimising the risks of component failure, unwanted noise and glitches getting back into the computer side of the wiring, any of which could result in damage to the computer and cause program crashes.

Fig.1 shows the RPI16OUT 16-bit optically isolated output board for the Raspberry Pi (to facilitate output connection the basic board, as supplied by Zeal electronics, is fitted with the male header part of a two-part 3.5mm spacing industrial connector)

The RPI16OUT has no less than 16 optically isolated outputs – but, if that's not quite enough for your particular application, up to eight similar boards can be easily daisy-chained (see later) to provide a massive total of 128 optically isolated outputs. Each of the 16 outputs can provide switching for voltages of up to 100V with currents of up to 60mA, sufficient for a wide range of loads. With minimal additional external circuitry (such as an external power driver, solid state or conventional relay) the board's capabilities can be easily extended to cope with more demanding loads in terms of both voltage and current. As with the other boards in the range, the RPI16OUT can be used with all current and past versions of the Raspberry Pi, including versions 1 and 2; types A, A+, B and B+; as well as the new single-board industrial Raspberry Pi Compute Module. The board also provides compatibility with any microprocessor system that has an industry-standard SPI interface.

Optical isolation

As mentioned in our RPIADCISOL review (Dec 2014, *EPE*) optical isolation of inputs and outputs can be instrumental in preventing high voltages (from the components being switched or monitored) damaging or interfering with the Raspberry Pi. For example, inputs could be

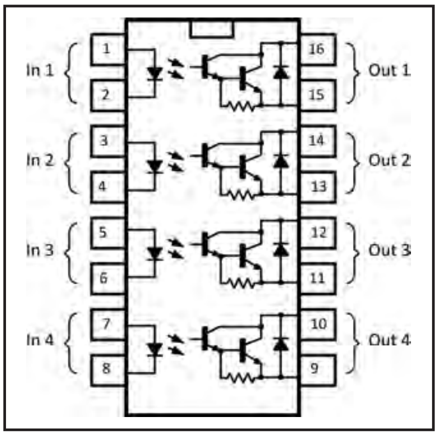


Fig.3. TheRPI16OUT'squadDarlington output drivers

derived from power-switching circuits that are several hundred volts above ground.

Without this optical isolation, the Raspberry Pi could easily be destroyed. Isolation considerably reduces the likelihood of impulse voltages and spikes getting back into the Raspberry Pi, which could cause it to crash or be damaged. Isolation is essential whenever sensitive electronic equipment like the Raspberry Pi is used in electrically harsh environments such as those found in most heavy industries.

The output opto-isolators fitted to the RPI16OUT are quad Darlington TLP627 output drivers. Usefully, these chips are fitted to the board using four low-profile 16-pin DIL sockets, so they can be easily changed if the need ever arises. The internal arrangement of the Darlington drivers is shown in Fig.3.

Very sensibly, the RPI16OUT's outputs are wired to the 3.5mm two-part connectors such that each output is made available in isolated pairs, arranged such that output 1 from the board is on pins 1 and 2, output 2 from the board is on pins 3 and 4, and so on.

Extending the output capability

Provided that loads operate from low-voltage DC supplies (typically 12V or 24V) and require a current of no more than about 60mA, the RPI16OUT can be used to drive a wide range of devices, such as low-current relays, indicators and contactors. To drive larger loads, such as actuators, motors and other high-current devices, it will be necessary to use an additional external interface. This might take the form of a power transistor, Darlington driver, solid-state relay (SSR), a small relay or miniature contactors (see Testing).

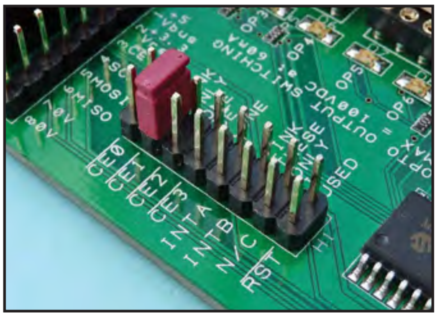


Fig.5. Configuration links used for address selection

Daisy chaining

Up to eight of the same RPI16OUT boards can be daisy-chained (see Fig.4) to give 8 × 16 = 128 optically isolated outputs. In this case, the first board will provide inputs 1 to 16, the second board will provide inputs 17 to 32 and so on. Each board will need to have its own unique address within the total address space available. For example, the first board will have address 000, the second 001, and so on. The board address can be set by means of three configuration links (see Fig.5).

When daisy chaining multiple RPI16OUT boards, it must be borne in mind that, since each board can demand up to 150mA of supply current, the current drain on the Raspberry Pi's power supply can be excessive. For this reason, a suitably rated external 5V DC supply should be used and the RPI16OUT's supply links (see Fig.6) should be set accordingly.

Auxiliary SPI

When using other computers or microprocessors (eg, Microchip PICs) their SPI interfaces can be connected to the RPI16OUT's auxiliary SPI connector (see Fig.2). To avoid damage to the Raspberry Pi's GPIO port, this header should not be used if the RPI16OUT is already connected to a Raspberry Pi.

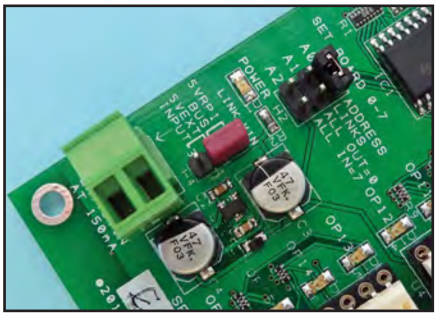


Fig.6. External supply connector and supply configuration links

Fig.4. Daisy chained RPI16OUT boards connected to a Raspberry Pi Model B

Board specification

Number of outputs	16 optically isolated digital outputs (expandable up to 128 outputs by adding up to seven further boards)
Switching capability	16 open-collector drivers for switching loads of up to 100V at up to 60mA (the output capability can be easily extended by using a wide range of suitably rated relays, contactors and power-switching devices – see text)
Turn-on time	5 to 50μs max (see note 1)
Turn-off time	15 to 80μs max (see note 1)
Output connectors	All outputs use standard 3.5mm industrial plug in screw terminal connectors, arranged in signal/ground pairs (the board is fitted with a male header to facilitate connection of the user's cabling via a two-part connector which must be purchased separately)
Status indicators	Individual LED status indicators for each channel
Voltage isolation	1kV max (see note 2)
Interface	Standard Raspberry Pi GPIO for digital I/O and high-speed SPI interface with Mode 0,0 and 1,1
Dimensions	60 × 135mm
Mounting	Four 3mm mounting holes at 52 × 127mm
Bus connector	The Raspberry Pi is connected via a standard 26-way GPIO ribbon connector (compatible with all current versions of the Raspberry Pi, including the Model A, A+, B and B+)
Power supply	+5V at 150mA (may be powered directly from the Raspberry Pi +5V bus or from an external +5V supply – see text).

Notes

1. Quoted turn-on and turn-off times are in addition to any delays imposed due to program execution.
2. The figure quoted here is the isolation test voltage. For typical use, the voltage present on the output lines should not normally exceed 24V.

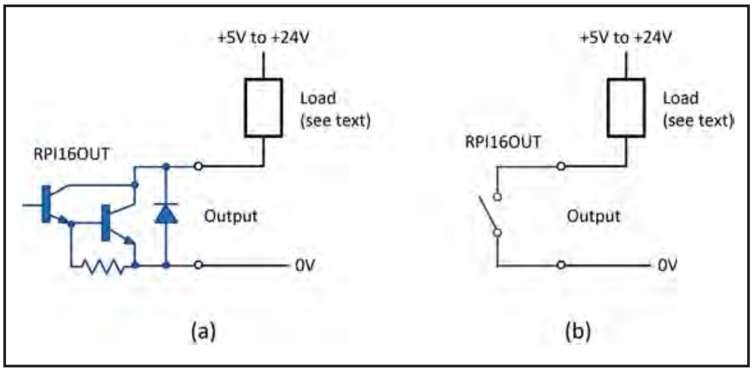


Fig.7. Output load connection

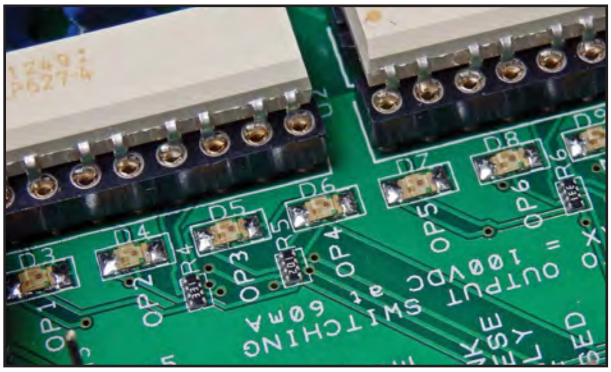


Fig. 8. LEDs show the status of the output signals

Documentation – example code

The RPI16OUT is supplied with an extensive and well-illustrated 101-page manual that provides full information on installing, connecting, using and programming the range of boards available from Zeal Electronics. The manual assumes that the reader has some familiarity with the C-programming language and, while C is a somewhat more obscure and prescriptive programming language than either BASIC or Python, a simple web search will provide newcomers with access to a vast repository of information, tutorials and example code.

The board is most conveniently programmed using the Raspberry Pi's built-in C compiler, GCC. Leafpad (or an equivalent text editor) will be required to write and edit your C source code, but all of the other files needed to compile an executable program are supplied with the RPI16OUT. They include all relevant header files, together with a sample C program and an associated make file. The code supplied can be freely used in any non-commercial applications, within education, and for home use as per the standard GNU v2 open source license. The source code files are efficient and commented in such a way as to make them easy to use and understand, and newcomers to C programming should have little difficulty in getting to grips with them.

Output limitations

Before connecting the board to an external load it is very important to be aware of the limitations of the RPI16OUT in terms of switched voltage and current. The Darlington isolator acts like a switch (see Fig.7) and it is connected in series with the load, which must have a separate supply (this will often be separate from the Raspberry Pi's and RPI16OUT supplies). While the load supply will normally be in the range +5V to +24V, it must never exceed the maximum allowable, 100V. Furthermore, the maximum rated load current is 60mA and this suggests that the load resistance for various voltages must not be less than the values shown in Table 1. The status of the output signals can be viewed from LED indicators fitted to the board, as shown in Fig.8.

The RPI16OUT was tested first with several strings of high-brightness LED Christmas lights driven directly from the Darlington outputs and then with a domestic fan motor driven via a small Omron 12V DPDT non-latching relay having a coil resistance of just over 1kΩ and requiring an operating current of around 12mA (see Fig.9). Relays of this type are typically rated for DC and AC loads of around 60W and 60VA respectively. They offer high dielectric strength with the ability to switch loads typically up to 2A at AC voltages of up to 250V (DC up to 220V).

Programming the RPI16OUT

As with the other two Raspberry Pi interface boards designed by Dr Stephen Alsop, it is quite easy to produce working applications for the RPI16OUT. That said, a working knowledge of C programming would be a distinct advantage – but, if you're not already familiar with C there's plenty on the web to help you get started.

Table 1: Minimum recommended load resistance for various supply voltages

Load supply	Minimum recommended load resistance
+5V	83Ω
+9V	150Ω
+12V	200Ω
+15V	250Ω
+24V	400Ω

Listings

1. A simple test loop that will turn all of the outputs on and off in turn

```
// Set loop range, eg FIRSTOUTPUT = 0 and LASTOUTPUT = 15
for (c=FIRSTOUTPUT;c<(LASTOUTPUT+1);c++) {
  // Turn an individual output on
  RPI16OUT_ON(c);
  delaymS(500);       // Hold it on for 0.5s
  // Turn the individual output off
  RPI16OUT_OFF(c);
  delaymS(250);       // Keep it off for 0.25s
} // for loop
```

2. Activate all 16 outputs on the first connected board (usually board 0)

```
b = FIRSTOUTPUT/16;   // b = board address which can range from 0 to 7
RPI16OUT_AllON(b);    // Turn all first board (b) outputs on
delaymS(500);         // Delay for 0.5s
```

3. Activate alternate outputs on the first connected board (usually board 0)

```
RPI16OUT_OLATAB_W(b,0xAAAA); // Turn alternate outputs on
delaymS(300);

RPI16OUT_OLATAB_W(b,0x5555); // Turn adjacent alternate outputs on
delaymS(300);
```

4. Send a bit pattern (1100111001110011) to the first connected board (usually board 0)

```
RPI16OUT_OLATAB_W(b,0b1100111001110011);    // Send 16-bit pattern
delaymS(300);                               // Delay
```

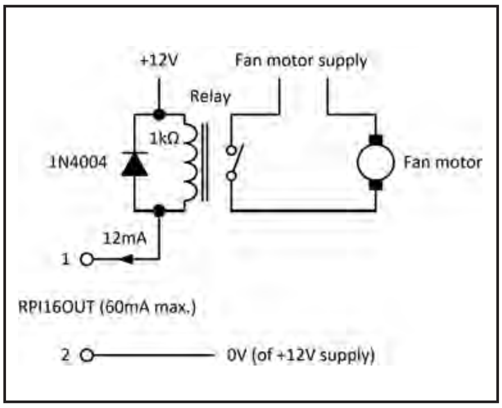


Fig.9. Fan motor test circuit using a suitably rated miniature relay

To the left are four brief code fragments that will show you just how easily the RPI16OUT is programmed. Further examples are available by completing an email demonstration software request from Zeal Electronics at: **www.zeal-electronics.co.uk/rpi/rpidownloads.html**.

Using contactors

If you intend to use this board in conjunction with a 24V heavy duty contactor (instead of a miniature relay) it is essential to ensure that the contactor coil is a DC type and is suitably rated. Many large industrial and domestic contactors have DC coils with resistance as low as 50Ω , and these require much more current than the Darlington outputs of the RPI16OUT can supply. The solution is to use an intermediate relay or (preferably) an additional, suitably rated, open-collector driver. Contactors with AC coils (which have a very low resistance) should never be used with boards of this type.

Other products from Zeal Electronics

In addition to the RPI16OUT, Zeal Electronics also supply two other high-specification optically isolated interface cards designed specifically for the Raspberry Pi. These boards can all be 'daisy chained' onto the Pi's GPIO bus and can be connected to the 26-way GPIO expansion connector in order to provide an extended digital I/O capability. We took a detailed look at the companion RPI16IN and RPIADCISOL isolated interface boards in previous issues of *EPE*.

Pricing

The RPI16OUT is priced at £33 plus VAT (with 10% discount for *EPE* readers). Bearing in mind the advantages of having a high degree of output isolation and the extensive supporting documentation supplied with these boards, this represents good value for money. Zeal Electronics can be contacted at: **www.zeal-electronics.co.uk/rpi/rpibuy.html**

In conclusion

Like the RPIADCISOL and RPPI16IN board that we reviewed earlier in *EPE*, this board could be a godsend if you find yourself working in an environment where a very high degree of electrical isolation is essential. But, if that's not the case, the board will still give you the added security of knowing that your Raspberry Pi has been given the benefit of a very high degree of protection from the ravages of the real world.

The RPI16OUT has an excellent specification and is well supported with liberally commented source code. Under test, the board performed exceptionally well and readers with only limited C programming experience should be able to get the board up and running quickly and easily. The interface represents good value and can be highly recommended for use in applications where input/output sensors and transducers may not be at true ground potential.

Oops!

Last, but not least, our thanks go to eagle-eyed *EPE* reader Norman Pomfret who spotted that we missed some information in our review of the RPIADCISOL board. The 3.5mm plug-in connectors are separate items and they need to be ordered separately. We should perhaps reiterate that this is because the Zeal Electronics boards make use of a standard industrial two-part connector system which is both electrically reliable and mechanically stable. The 3.5mm plug-in connectors shown in several of our illustrations are supplied as separate items (at reasonable cost) but they allow readers to connect to existing wiring looms without having to purchase a board fitted with an unwanted duplicate set of plug-in connectors. We are sorry that we did not mention this in the review.

Constant current sources – Part 2

LAST month, we started looking at current sources in response to a post by ***atferrari*** in the *EPE Chat Zone*. The question posed by ***atferrari*** was answered later in the thread, but it had highlighted an interesting topic for *Circuit Surgery* to discuss in more general terms, which we will continue here – we will also look at a specific solution. First, a quick reminder of atferrari's post:

After reading about constant current sources, I defined four cases, see Fig.1. Current should go up to 250mA. Implementing B and C with Fig.2 and its counterpart is straightforward, but I am not sure how to proceed for A and D. I cannot have Rsense referred to ground anymore. How should proceed without fancy ICs?

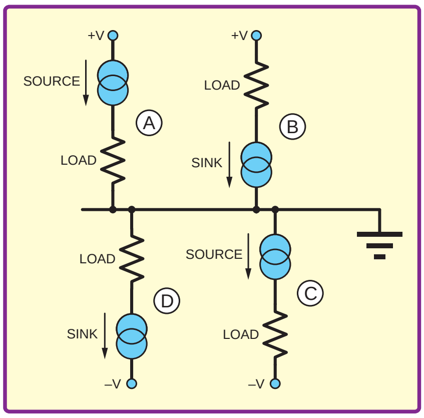


Fig.1. Current source cases from ***atferrari's*** Chat Zone *post (see question text)*

Recap the basics

We looked at the basic concept of current sources, which are perhaps less familiar than voltages sources, where we have batteries and the mains as everyday examples of 'good' voltage sources. In circuit analysis we often make use of ideal voltage and current sources to simplify analysis. Ideal sources do not exist in the real world, they are mathematical constructs only, but they are useful. For example, we frequently assume the power supply of a circuit is an ideal DC voltage source. This means we don't have to worry about things like loading effects or supply noise, thereby reducing analysis effort and complexity.

Of course, sometimes we are interested in the performance of a voltage or current source and have to consider their non-ideal characteristics. The most fundamental of these is the internal resistance (see Fig.3), which limits the maximum current from a voltage source and the maximum voltage from a current source.

As we saw last month, the internal resistance, R_{int}, of a current source, I_S, limits its output voltage to $I_S R_{int}$ (Fig.3), at which point I_{out} is zero – the larger the value of R_{int}, the larger the maximum output voltage. For ideal current sources R_{int} is infinite and the open circuit output voltage is infinite. If we short circuit a current source the output current is equal to I_S and there is zero voltage across the source.

Real current sources may also have a limited range of voltages over which

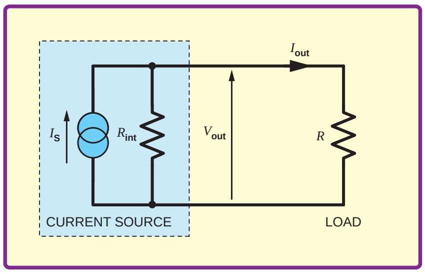


Fig.3. Internal resistance of a real current source

they can operate (sometimes called *compliance*), determined by factors other than the internal resistance. Typically, these current sources are built from active electronic circuits using transistors and op amps. Particularly for those circuits using feedback to maintain the current, the internal resistance might be much higher than indicated by the current supplied at the maximum working output voltage (Fig.3).

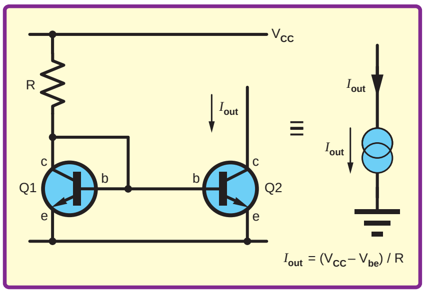


Fig.4. Constant current source (sink) based on a current mirror – Q1 and Q2 are matched transistors

Often, a real current source circuit will cut off, or stop acting as a current source if the voltage needs to go beyond a certain point to maintain the current. The ratings and characteristics of the circuit structures and components, and often the supply voltage, limit the voltage range at the output. For example, in the basic bipolar transistor current source shown in Fig.4 (discussed last month), *Q2* will stop working correctly if the required output voltage is below the minimum voltage at *Q2's* collector (with it conducting). This is its saturation voltage (typically about 0.2 to 0.3V). Furthermore, the circuit is limited by the maximum collector-emitter voltage rating of *Q2*.

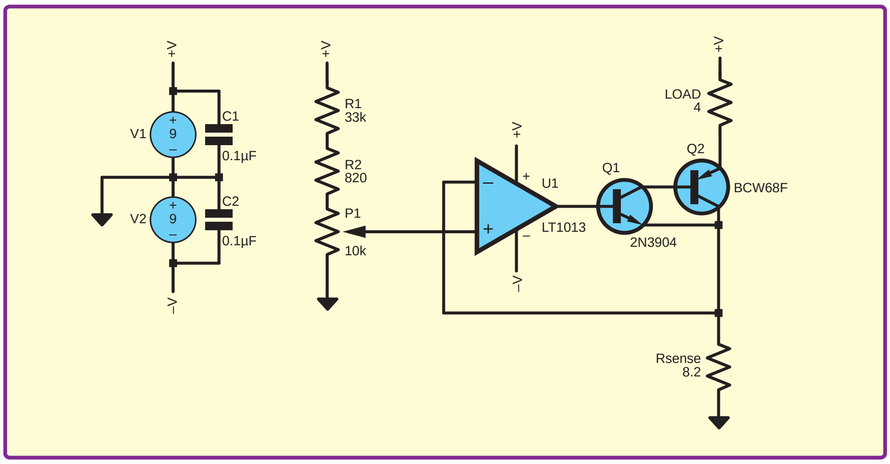


Fig.2. Schematic from ***atferrari's*** Chat Zone *post (see question text)*

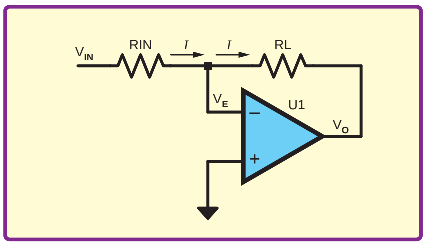


Fig.5. Floating load op amp current source

Op amps

This month we will move on to look at three op-amp-based current source circuits, including the one discussed in ***atferrari's*** *Chat Zone* thread. These circuits do not constitute an exhaustive list of op-amp-based current sources, but will provide some insight into the variety of techniques available.

The circuit in Fig.5 is a standard inverting op amp amplifier; we can regard the feedback resistor as a load to which a constant current is supplied if the input voltage is held constant. This circuit does not conform to one of the scenarios in Fig.1 – the load is floating – it is not connected to either a supply or ground. It is, therefore, not suitable for loads which have to have one end connected to ground or a supply.

By virtue of the op amp's very high gain, the inverting input must be at a voltage close to zero if the output is not to be saturated. Thus, the inverting input behaves as if it is connected to ground and is known as a 'virtual earth' or 'virtual ground' (ie, $V_E \sim 0$). Consider an op amp with a gain of 1 million. If the output is, V_O = 10V, then V_E will be 10µV (V_E = 10/1,000,000). If V_{IN} is more than a few millivolts V_E can be reasonably approximated to zero without, for example, resulting in a significant error in calculating I.

Assuming $V_E = 0$, the current through R_{IN} is simply $I = V_{IN}/R_{IN}$, just as if R_{IN} was actually grounded. However, this current does not actually flow to ground – it can only go to two places: into the op amp or through the feedback resistor. If the op amp has very high input impedance (a reasonable assumption for many op amps) and the feedback resistor is not excessively large then the vast majority of the current will flow through the feedback resistor (R_L). This current will be $I = V_{IN}/R_{IN}$, as previously stated, and is therefore independent of the value of R_L. If V_{IN} is held constant the current in R_L will be nearly constant even for quite large variations in R_L.

Variants of the circuit in Fig.5 were often used to convert mechanical ammeters to read voltage (or some other quantity sensed or measured as a voltage). The feedback current is proportional to the input voltage, independent of the meter's resistance and can be scaled as required. Of course, electromechanical meters are less common now, so perhaps this circuit is less widely used.

The circuit has the disadvantage that the voltage input must supply a current equal to I. This can be overcome by using another op amp to provide gain/buffering. Alternatively a standard non-inverting amplifier will work in a similar way (with the feedback resistor as the load), but with a high input impedance for the controlling voltage.

The circuit in Fig.5 is not an ideal current source. The voltage across the load is limited by the output voltage range of the op amp (typically up to/close to the supplies). The current will not be completely independent of R_L due to non-ideal operation of the op amp.

Howland current source

The circuit show in Fig.6 is the basic form of a circuit known as a 'Howland current source' (or Howland current pump). The circuit resembles a standard op amp differential amplifier; it would have the same topology if R_4 was not there. R_4 is interesting in that it provides *positive* feedback. An advantage of the Howland current source is that, unlike the circuit in Fig.2, it can either sink or source current; which is determined by the polarity of V_{IN} in Fig.6. Thus, the single circuit covers cases *B* and *C* in Fig.1.

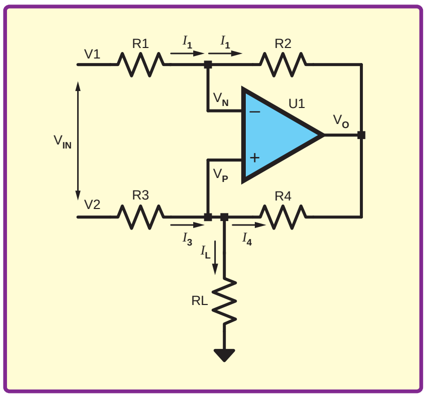


Fig.6. Basic Howland current source

Like the differential amplifier it must have matched resistor ratios, in this case $R_2/R_1 = R_3/R_4$ is required. In many implementations all four of these resistors have the same value. Since it is a differential circuit, the input voltage V_{IN} is applied between the two inputs, rather than referenced to ground; but we can also consider the voltage on the two inputs separately as V_1 and V_2. Furthermore for an op amp with very high gain, which is not saturated (ie, normal operation), we can assume that its input terminal voltages are effectively equal ($V_N = V_P = V_X$). This is similar to the idea of the virtual earth for the circuit in Fig.5.

As with the circuit in Fig.5, we assume that no current flows into the op amp in the circuit in Fig.6 due to its high input impedance. Thus the current in R_1 will be the same as the current in R_2. So we can write:

$$I_1 = (V_1 - V_X)/R_1 = (V_X - V_O)/R_2$$

This expression is simply Ohm's law, relating voltage across the resistors to the current through them. Because the resistor ratios are designed to be equal, that is $R_2/R_1 = R_3/R_4$, we can also write this equation as:

$$I_1 = (V_1 - V_X)/R_3 = (V_X - V_O)/R_4$$

The current in R_3 will be:

$$I_3 = (V_2 - V_X)/R_3$$

And the current in R_4 is:

$$I_4 = (V_X - V_o)/R_4$$

However, unlike the currents in R_1 and R_2, I_3 and I_4 are not equal. I_3 splits and flows through R_L and R_4. Again, assuming no current into the op amp, Kirchhoff's Law tells us that I_3 is equal to the sum of I_4 and I_L, that is:

$$I_3 = I_L + I_4$$

Substituting the voltage/resistance expressions (from above) for the currents into this expression we get:

$$(V_2 - V_X)/R_3 = I_L + (V_X - V_O)/R_4$$

But looking at the second version of our equation for I_1, we see $(V_X - V_O)/R_4 = (V_1 - V_X)/R_3$, so we can write this as:

$$(V_2 - V_X)/R_3 = I_L + (V_1 - V_X)/R_3$$

V_X cancels in this equation, and then we can rearrange it to get:

$$I_L = (V_2 - V_1)/R_3$$

Thus, the current in the load does not depend on the value of R_L and is set by the differential input voltage and R_3.

Imperfections

Like all circuits this has its limits and imperfections. One problem is that the circuit depends on exact matching of the resistor ratios. Precision resistors (0.1% or better) should be used, otherwise the internal resistance of the current source may not be very high (it can even be negative).

A disadvantage of the basic Howland current source is its restricted voltage range. V_O is larger than the voltage across the load, so if the load voltage

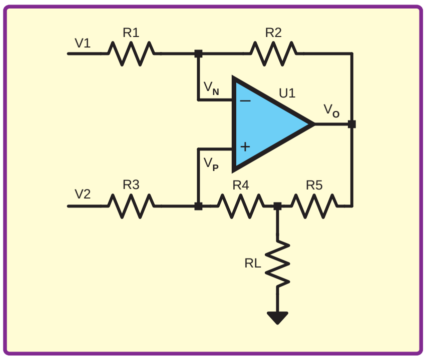


Fig.7. Improved Howland current source

needs to increase to maintain the current, the op amp will saturate before the load voltage is anywhere near the supply. The circuit in Fig.7 is a modified version of the Howland current source, which overcomes some of the issues with the basic design, including the voltage range.

In the circuit in Fig.7, R_4 from Fig.5 is split into R_4 and R_5. R_5 is much smaller than R_4, so the voltage drop across R_5 in Fig.7 is much less than for R_4 in Fig.6. This means that the load voltage is much closer to op amp output voltage and output range is not 'wasted' on the R_4 drop. The circuit in Fig.7 requires the resistor ratios to be matched such that:

$$R_2/R_1 = R_3/(R_4 + R_5)$$

As with the basic circuit, high precision resistors must be used to achieve accurate matching of these ratios if good performance (high internal resistance of the current source) is to be achieved. In both circuits, it is possible to use various trimmer arrangements to allow the matching to be adjusted.

Op amp and transistor

The circuit in Fig.8 is the simplest version of a circuit which fits the requirements of ***atferrari's*** question in that the load and sense resistors are the opposite way round to the circuit in Fig.2. The transistor can be replaced by a Darlington pair or MOSFET – the basic principles of operation are the same.

The circuit in Fig.8 (and similarly Fig.2) is a feedback system that regulates the current though the load (I_{LOAD}) by matching the voltage at the sense resistor (V_{SENSE}) to the input reference voltage, V_{IN}. The current in the load is approximately equal to the current in the sense resistor. Controlling the voltage across the sense resistor controls the current through it and therefore also sets the load current.

As with the other op amp circuits discussed, we can assume that the voltage between the two op amp inputs

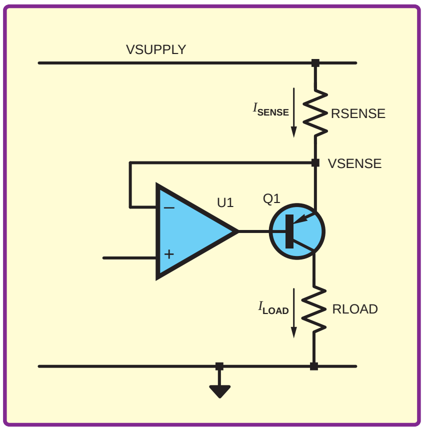


Fig.8. Current source with grounded load

is close to zero. We also assume that no current flows into the op amp. The first assumption means that the voltage at the sense resistor, V_{SENSE}, is equal to V_{IN}. The second assumption means the op amp does not load or disturb the voltage at the sense resistor. The current is:

$$I_{LOAD} = I_{SENSE} = (V_{SUPPLY} - V_{SENSE})/R_{SENSE}$$

But: $V_{IN} = V_{SENSE}$

So: $I_{LOAD} = (V_{SUPPLY} - V_{IN})/R_{SENSE}$

As with the other circuits this expression shows that the load current is independent of R_{LOAD} and controlled by the input voltage. However, as before, this is based on the assumption of idealised op amp behaviour, so it will not be totally true for a real circuit. As the input is connected only to the op amp's non-inverting input, very little current is required from the reference voltage source.

The load current and sense resistor currents only match approximately because of the base current in the transistor. This situation can be improved by using a pair of transistors – Darlington or Sziklai (as in Fig.2) – or a MOSFET. The transistor pairs have much higher current gain than a single transistor, so the effective base current is much lower. A MOSFET will have no input current if the voltage at its gate is more or less constant.

Common mode

The sense resistor is typically a relatively low value, if this were not the case then it would drop a significant voltage and therefore restrict the range of possible voltages across the load (required to maintain the current as the load varies). The transistor's minimum emitter-to-collector voltage is the saturation voltage, as we discussed for the circuit in Fig.4; thus, the maximum voltage across the load is a little lower than V_{IN}.

The small voltage drop across the sense resistor means that V_{SENSE} and V_{IN} are close to the supply. This means that the op amp must be able to cope with common-mode inputs close to the supply. The term 'common mode' refers to the fact that it is the voltage at both op amp inputs we are concerned about, as opposed to the difference between them (what it actually amplifies). Strictly speaking, the common-mode voltage is the average voltage at the two inputs, but since we are assuming they are effectively equal, we can simply take the common-mode voltage as being equal to V_{SENSE} or V_{IN}.

Not all op amps can operate correctly, or perform well with common-mode inputs close to the supplies, so a device specified for 'rail to rail' common-mode input must be used. The term 'rail to rail' is also used to describe op amp output capabilities, so care is needed when checking device specifications. The situation is easier with the circuit in Fig.2 – the grounded sense resistor means that the common-mode input voltage is relatively small.

In this article we looked at three op-amp-based current sources. In each case, circuit operation is dependent on negative feedback. With all feedback circuits there is potential for instability and practical implementations often include a small capacitor (maybe 5pF to 10pF) across the feedback resistor (where one is present) to improve stability.

By Robert Penfold

INTERFACE

Multi-channel analogue inputs

THE previous Interface article described a 12-bit analogue-to-digital converter for the Raspberry Pi computer. This was a single-channel design based on an MCP3201 chip. With the aid of some additional hardware it would be possible to provide the original design with multichannel operation, and the GPIO port of the Raspberry Pi has plenty of outputs that could be used to control some analogue switches. However, this would certainly be doing things the hard way, since there are multi-channel versions of the MCP3201 that have a built-in multiplexer.

Cost-effective approach

The device versions in question are the MCP3204 and MCP3208, which respectively provide four and eight analogue inputs. Although multichannel versions of analogue-to-digital converters are sometimes relatively expensive, in this case there seems to be very little difference in price between the single and multi-input versions. The MCP3204 and MCP3208 are therefore very cost-effective ways of providing a computer with several analogue inputs.

As before, 12-bit resolution is provided, giving an output range of 0 to 4095. This is sixteen times the resolution of an 8-bit converter, which should be more than adequate for most real-world applications. Of course, the MCP3204 and MCP3208 each contain only a single analogue-to-digital converter, and respectively have built-in four and eight-way multiplexers. This means that the inputs must be handled one at a time, and the maximum conversion rate per channel is reduced in line with the number of channels in use. However, in practice it is likely that the software rather than the hardware will be the limiting factor.

The chips are capable of a respectable 100,000 conversions per second. Running a Python program on a Raspberry Pi it is likely that no more than a few thousand conversions per second could be achieved. With eight channels in operation this would be reduced to several hundred conversions per second per channel. This is still more than adequate for many practical measurement and control applications.

On the hardware side of things, all three chips use essentially the same method of interfacing to the computer. They all use a simple three line synchronous serial interface to initiate conversions and clock the data out of the chip. The multi-channel chips require four bits of data to be sent from the computer to select the required mode and channel. This information is carried in asynchronous serial form by a fourth line. In other words, the multi-input chips have a two-way synchronous serial link with the computer, using a common clock signal.

Whatever version of the Raspberry Pi is in use, most of the GPIO port's input/output lines will still be available for other purposes, even if a MCP3208 is being used to provide eight 12-bit inputs. A parallel interface equivalent would require about sixteen or seventeen input/output lines. Interfacing to an MCP3204 or MCP3208 requires only four input/output lines, which leaves a standard Raspberry Pi with plenty in reserve. Serial interfacing is relatively slow, and the programming is less straightforward, but it is very economic in terms of the number of data and control lines required. It also avoids the necessity for huge ribbon cables.

Little and large

Pin functions for the MCP3201, MCP3204 and MCP3208 are shown in Fig.1. These, respectively, have 8, 14, and 16 pin encapsulations, but pins 5 and 6 of the MCP3204 are unused. All three chips are available in various case styles, including the ordinary DIL (dual in-line) variety. The MCP3201 has common analogue and digital ground connections, but the other two chips have them available at separate pins. In practice, the two ground pins are normally just connected together externally.

As pointed out previously, the basic method of interfacing to the computer is achieved using the same three-line method for all three chips, but with an additional line for the multichannel chips. The negative chip select input is taken low to activate the chip, start a conversion, and initiate communication between the converter and the computer. Clock cycles are then applied to the clock input, and the serial data appears on the data output, starting with the most-significant bit (D11) and working in sequence through to the least-significant bit (D0).

Same difference

Apart from the number of inputs, there are some other significant differences on the analogue side of things. The MCP3201 has differential inputs, albeit with some limitations on the negative input. There are no negative inputs on the MCP3204 and MCP3208 chips, but the normal analogue inputs can provide a form of differential operation. This is achieved by using the analogue inputs in pairs (CH0/CH1, CH2/CH3…). The MCP3204 can, therefore, have four single-ended inputs, or two differential inputs. The MCP3208 can operate with eight single-ended inputs or four differential pairs.

The required channel and mode of operation is selected via four bits of data sent to the converter chip's data input via the fourth line. This data is sent just after the chip is activated via the negative chip select input. The first bit is used to select

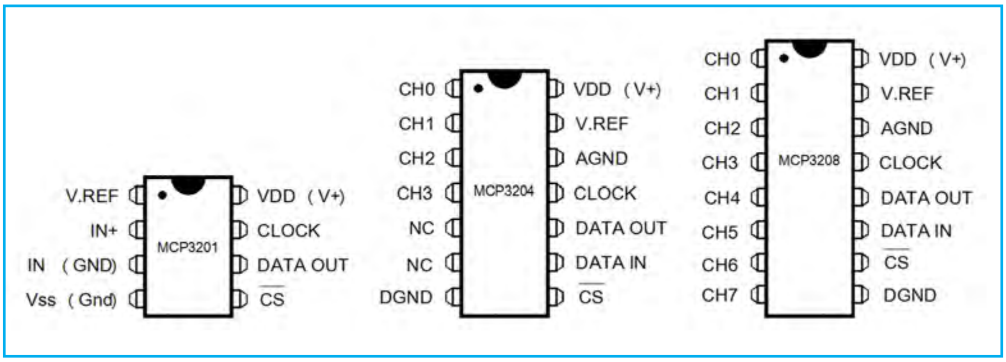


Fig.1. Connection details for the MCP3201, MCP3204, and MCP3208 (single-, four-, and eight-channel converters. The multichannel chips each contain a single analogue-to-digital converter, with a built-in multiplexer providing the multiple inputs

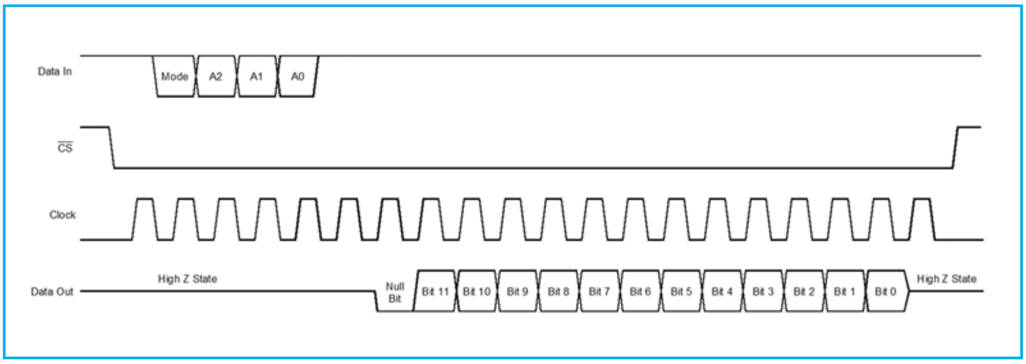


Fig.2. The timing diagram for the MCP3204 and MCP3208 chips. These use the same three-line connection to the computer as the MCP3201, plus an extra line so that the computer can select the input mode and the required channel

either single-ended or differential operation, and the next three bits are used to choose the required input. Three bits of address information are required with the MCP3204, even though only two are needed in order to address four inputs. The first of the address bits is irrelevant, and it can be set at either state.

Fig.2 shows the timing diagram for the MCP3204 and MCP3208 converter chips. A conversion and reading sequence starts with the chip select input going through a high-to-low transition. The computer then generates a clock cycle, places the appropriate state on the converter chip's data input, and then generates another clock cycle. It is this second clock signal that results in the bit of data being read by the converter. This bit selects differential (low) or single-ended (high) operation. It is on the low-to-high transition of the clock cycle that data is latched into the converter chip.

The same process is repeated on the next three clock cycles, with the address data that selects the required input being transferred to the converter. The next clock cycle switches the converter chip from the read mode into the write one, but the first bit of data produced on the following clock cycle is a null bit. This is always low and should be ignored. It is on the next clock cycle that the most-significant data bit is placed on the converter's data output. This bit is read by the computer, another clock pulse is generated, bit 10 is read, and another clock pulse is generated, and so on until all twelve bits have been read. It is then just a matter of returning the chip select input to the high state so that the system is ready to start another conversion.

Four-channel circuit

The circuit diagram for a four-channel analogue-to-digital converter based on an MCP3204 is shown in Fig.3. This is much the same as the single-channel circuit featured in the previous *Interface* article, but with the data input of the converter chip driven from GPIO24 (pin 18) of the GPIO port. The other three connections to the converter chip are as before, as is the use of a TL431C to provide a stable reference potential of 2.5V. An input voltage range of 0 to 2.5V is therefore obtained on all four channels. Interfacing to the MCP3208 could use the same method of connection.

The MCP3204 used for IC1 is a MOS device, so standard anti-static handling precautions should be observed. Connection details for the TLC431C are shown in Fig.4.

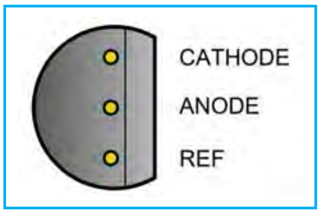


Fig.4. TL431C regulator connection details (top view, not a transistor-style base view)

Table 1

M0	A2	A1	A0	Input mode	Channel
1	0	0	0	Single-ended	Ch0
1	0	0	1	Single-ended	Ch1
1	0	1	0	Single-ended	Ch2
1	0	1	1	Single-ended	Ch3
0	0	0	0	Differential	Ch0+, Ch1-
0	0	0	1	Differential	Ch0-, Ch1+
0	0	1	0	Differential	Ch2+, Ch3-
0	0	1	1	Differential	Ch2-, Ch3+

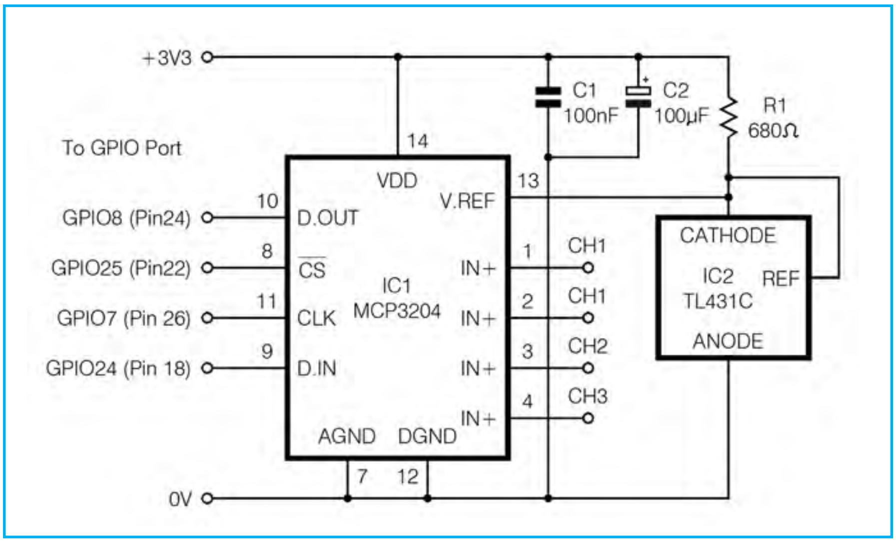


Fig.3. The circuit diagram for a 12-bit serial analogue-to-digital converter based on a MCP3204. It is possible to use the same method of interfacing to the GPIO port if a MCP3208 is used

In control

Table 1 shows how the mode and three address bits are used to select the required input mode and channel when using the MCP3204, and when using channels 0 to 3 of the MCP3208. In order to use channels 4 to 7 of an MCP3208, it is just a matter of setting A2 high (1) instead of low (0). A2 is a so-called 'don't care' bit when using the MCP3204, and it can be low or high. Even though it serves no useful purpose, it must still be included because the internal logic circuits of the chip expect this bit to be present.

Software

The Python program of Listing 1 can be used to test the converter. I used this program with a converter based on the MCP3204, but it should work equally well with one based on the MCP3208. It is a modified version of the software for the MCP3201 that was described

Listing 1

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)
GPIO.setup(22, GPIO.OUT)
GPIO.setup(24, GPIO.IN)
GPIO.setup(26, GPIO.OUT)
GPIO.setup(18, GPIO.OUT)
GPIO.output(22, GPIO.HIGH)
GPIO.output(26, GPIO.LOW)
GPIO.output(18, GPIO.HIGH)
Readings = 0
Average = 0

while(Readings < 10):
    dataword = 0
    GPIO.output(22, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output (18, GPIO.HIGH)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output (18, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output (18, GPIO.HIGH)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output (18, GPIO.HIGH)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)

    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B11 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B10 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B9 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B8 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B7 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B6 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B5 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B4 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B3 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B2 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B1 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B0 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(22, GPIO.HIGH)
    GPIO.output(18, GPIO.HIGH)
    if B11:
      dataword = dataword + 2048
    if B10:
      dataword = dataword + 1024
    if B9:
       dataword = dataword + 512
    if B8:
       dataword = dataword + 256
    if B7:
       dataword = dataword + 128
    if B6:
       dataword = dataword + 64
    if B5:
       dataword = dataword + 32
    if B4:
       dataword = dataword + 16
    if B3:
       dataword = dataword + 8
    if B2:
       dataword = dataword + 4
    if B1:
       dataword = dataword + 2
    if B7:
       dataword = dataword + 1
    Average = Average + dataword
    Readings = Readings + 1

print (Average/10)
GPIO.cleanup()
print ("Finished")
```

in the previous Interface article. The initial section of the program has been modified to set GPIO24 (pin 18 of the GPIO port) as an output that is used to send serial data to the converter chip. Reading data from the chip is accomplished in the same way as before, and this is the function of the final section. It actually takes ten readings in rapid succession and then averages them. This can help to minimise problems with noise on the input signal.

The middle section of the program handles setting the input mode and selecting the required channel. First, the converter chip is activated, and then the four bits of data are clocked into the chip. In this example the first bit is high, and single-ended operation is therefore produced. The next three bits are low, high and high, which selects channel 3. Remember that the most-significant address bit (A2) is sent first. When using these or any other computer interfacing devices, it is advisable to download the data sheets from the Internet. The MCP3204/8 data sheet includes useful information about the limitations of the differential input mode, and using the separate analogue and digital grounds.

Max's Cool Beans

By Max The Magnificent

Reinventing USB

One of the more useful innovations over the past few years has been the widespread deployment of the Universal Serial Bus (USB). I think it's fair to say that some of our younger readers would have trouble imagining a world without USB – because they don't remember a time before USB!

Everyone has USB 2.0-enabled devices. Some folks even have USB 3.0-enabled devices. But now a new type of USB is heading our way – USB Type-C – and this next-generation technology is going to make our heads spin and blow our socks off.

The world before USB

When I was a young engineer in the early 1990s (the Dark Ages) we never dreamt of something as wonderful as USB. We had to battle our way through life using a bewildering array of connectors. (see the wonderful xkcd cartoon – **http://xkcd.com/1406**)

We had one PS/2 connector for the mouse and another for the keyboard, but these devices weren't interchangeable because they used different commands. Next, there would be one or two RS-232 serial ports, which would be used to connect the computer to a variety of external devices such as scanners, plotters and external modems. There would also be a parallel port, which would be used to drive a printer, and perhaps a SCSI port for use with external storage devices.

A real downside to a lot of these connectors was that they weren't hot-pluggable; you had to power your computer down before you connected a device to it. One of my chums didn't believe this to be true – he found out the hard way when he plugged a PS/2 keyboard into a computer while it was powered up and toasted the motherboard.

Another issue was that computers provided only a limited number of ports – two RS-232 connectors if you were lucky. If you wished to connect additional devices, you had to add an expansion card to your machine. Plus, if you did connect a new device, you would have to install an appropriate driver from a floppy disk. It makes my head ache just thinking about it.

USB 1.0 to 3.1

In 1994, a group of seven companies (Compaq, DEC, IBM, Intel, Microsoft, NEC, and Nortel) came together to address these issues. The resulting USB 1.0 standard was released in 1996, but there were 'issues' and few USB 1.0 devices actually made it to the market. Everything was sorted out by 1998 when USB 1.1 was released, and end-users took their first tentative steps into the golden age.

USB 1.x specified data rates of 1.5Mbps (megabits per second; Low Speed) and 12Mbps (Full Speed). In 2001, the USB 2.0 release boosted this up to 480Mbps (High Speed), which was followed by USB 3.0 in 2008, which increased the bandwidth to 5Gbps (SuperSpeed), which was boosted up to 10Gbps (SuperSpeed+) for the 2013 USB 3.1 release.

USB brings many cool properties to the table. First, USB-enabled devices are hot-pluggable, you can connect them to your computer without having to power it down. If you connect a new USB device to your computer, the system automatically tracks down and installs an appropriate driver. If you run out of USB ports, all you need to do is plug in a cheap-and-cheerful USB hub, and off you go again. And the availability of USB has spawned all sorts of innovative products – can you imagine life without USB memory sticks?

However, there is room for improvement. For example, USB plugs are polarised, which means you have to work out which side is 'top' before plugging it in. Also, there are different connectors at each end of the cable – speaking of which, the number of connector types has proliferated. First there was Type-A and Type-B, then Mini-A and Mini-B, and next Micro-A and Micro-B.

Introducing USB Type-C

For the past few years, the folks at the USB Implementers Forum (USB-IF) have been beavering away, and come up with something rather clever: USB Type-C.

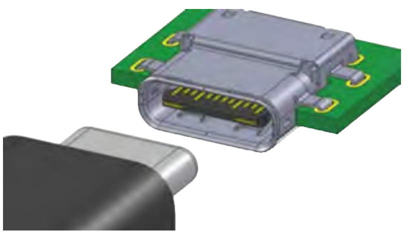
Let's start with the physical connector itself, which boasts 24-pins, is small (3mm high and 8mm wide), and robust (it's rated for 10,000 mate/de-mate cycles). One of the really cool things about this connector is that it is non-polarised, which means it will plug in either way. Also, this connector will be used on every device (PC, tablet, smartphone, camera) and the same Type-C plug will appear on both ends of the cable.

In addition to supporting legacy USB 1.x, 2.0, and 3.x modes, the new scheme boasts dual high-speed channels that can support two USB 3.1 streams, thereby boosting the bandwidth up to 20Gbps. Furthermore, these high-speed channels can be used to convey alternate data modes, such as video (VGA, HDMI, Display Port). There are also two 'side-band' channels that can be used for lower bandwidth vendor-specified data, such as an audio stream.

Also, USB Type-C can deliver up to 100W for faster charging. In the case of the simpler power delivery and data transmission modes, passive (unintelligent) cables may be used. When it comes to the more advanced modes, intelligent cables will be required, these will contain an electronic ID that can tell other elements in the system the cable's power capacity and the data bandwidths it can handle.

Out now!

USB Type-C was demonstrated at CES 2015 and we can expect to see USB Type-C-enabled products by mid-2015 – I can't wait!



View looking into a surface-mount USB Type-C socket

AUDIO OUT

By Jake Rothman

Ge-mania – Part 1

History

On 17 November, 1947 John Bardeen and Walter Brattain at AT&T's Bell Labs performed experiments and observed power amplification of a signal applied to a semiconductor crystal. Together with William Shockley they had invented the transistor, and in 1956 the trio were awarded the Nobel Prize in Physics 'for their researches on semiconductors and their discovery of the transistor effect'.

So what was in this special crystal – silicon? Definitely not – it was germanium, and for a short period the future looked germanium flavoured. However, as we all know, there is no Germanium Valley and we don't use germanium chips. Commercially, the germanium era only lasted from 1957 to around 1972, a mere 15 years, and even then it was dominant for just a few of those years – but it did usher in modern electronics – the germanium era was the first stage of the transistor solid-state age, which coincided with the moon race and the arrival of transistor radios.

Who still uses germanium?

Like many lost technologies, germanium devices have their adherents. 'Who would want a temperature-sensitive, inconsistent, obsolete, scarce and expensive device in their designs?', I hear you ask. Well, it's the retro-loving, valve-hugging music buff! I used to call it 'germania' – although strictly speaking it should be 'ge-mania', since 'germania' is simply Latin for Germany, the original source of the element's name. Anyway, satisfying the demand for ge-manophiles is part of my job, and I do my best to give ge-maniacs the gear they want!

It's difficult to get germanium devices today. Most are Cold War legacy, 'new-old-stock' from electronic shops and specialist component suppliers, such as Cyclops, often in the north of England. Because the stock can be over 50 years old, 20% of what I buy doesn't even work. Some specialist germanium devices are still made in the States, but for their infra-red optical properties – not for audio use. Apparently, Doug Dunlop had some made recently for 'Fuzz Face' guitar effect pedals; they must have been expensive, since the price of raw germanium today is 80× that of silicon. Interestingly, the germanium used to be extracted from the soot of flue gasses of coal-fired power stations. There were also ores available from a few conflict zones. It was the difficulty in refining high-purity silicon at elevated temperatures that initially precluded its use, despite it being the second most common element in the Earth's crust. In 1958, a typical germanium small-signal transistor cost around £1.40 retail (today's money).

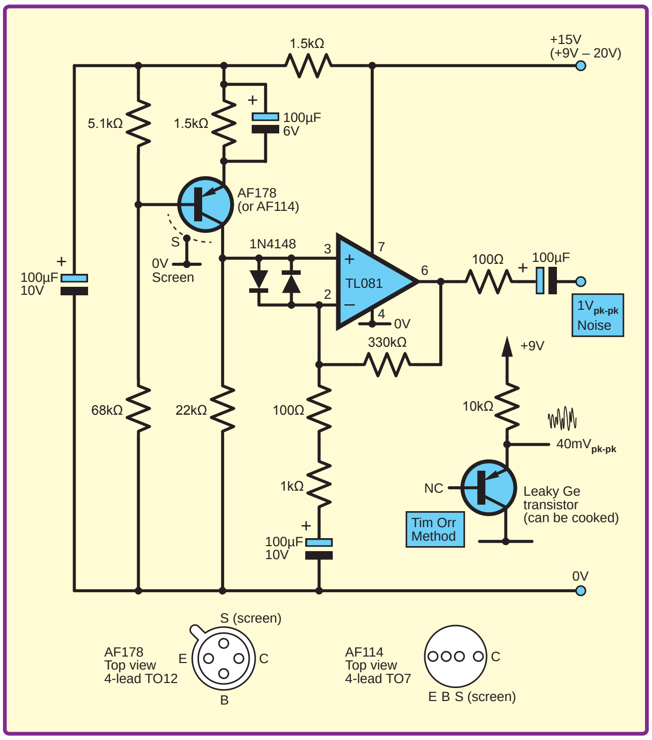


Fig.1. RF Germanium transistors make excellent white noise generators. Some often have a 'spluttery' noise character, they are useful for analogue drum units, since every 'hit' sounds different.

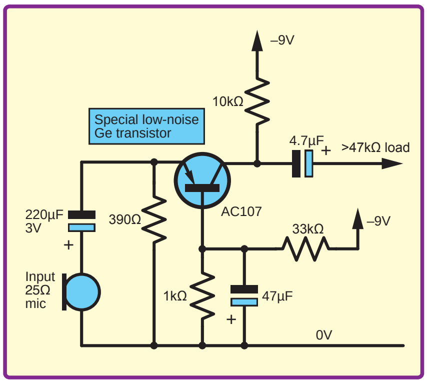


Fig.2. Common-base germanium microphone pre-amp. Used in the sixties to connect low impedance moving-coil microphones to high-impedance valve inputs.

I have some old germanium alloy-diffused RF transistors (AF128) that produce the most sonically interesting noise (I suspect there are some radioactive contaminants from the coal and crystal defects at work here) and I use these in analogue drum synthesisers – see Fig.1. In theory, germanium-alloy transistors, such as the 2N508A, can give the lowest voltage noise, giving lower noise than silicon planar devices with low impedance sources, such as ribbon microphones. However the poor manufacturing of old devices means you would have to manually select from a large number to get good results.

In my practical experience, modern silicon devices are generally quieter. Fig.2 shows a common-base preamp, which has a low input and high output impedance. It uses an AC107, a special low-noise germanium transistor designed for tape recorders in 1964. Hooking it up to a 25Ω moving-coil microphone gave good results – acting like a matching transformer. There are some germanium pre-amps and compressors

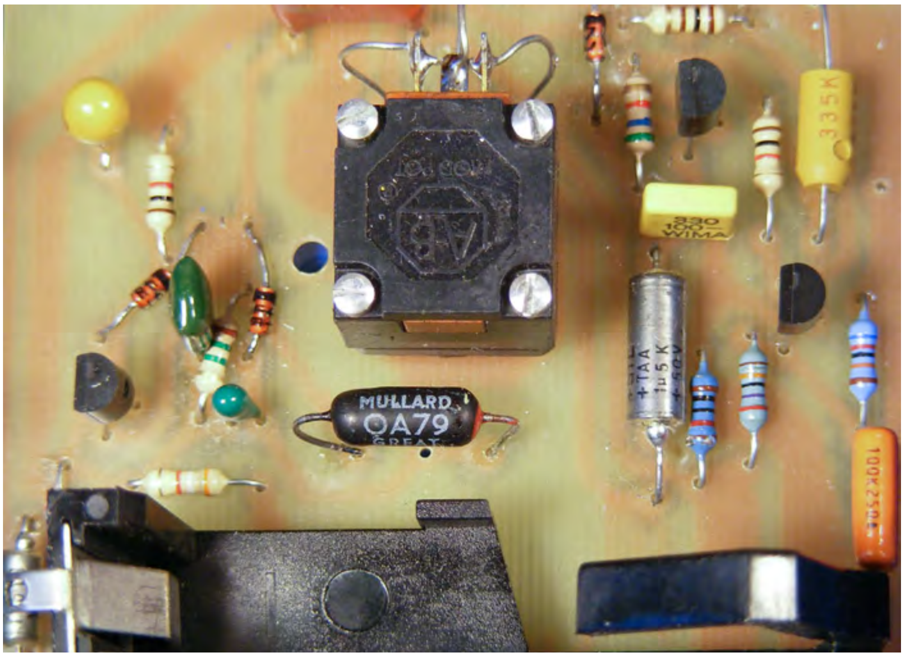


Fig.3. The earliest mass-produced semiconductor, the point-contact diode. Here, a 1960 OA79 is used in a Colorsound Single Knob Fuzz effects box, along with a silicon diode to give asymmetrical clipping action.

on the market, such as those by Chandler Ltd. There is renewed interest in germanium for heterojunction bipolar transistors where germanium is combined with silicon in the base region of the device. They are used in very low-noise microwave applications.

Germanium vs silicon

The first mass-produced semiconductors were germanium point-contact diodes, such as the OA81 and OA79. I use OA79s in the latest version of my Colorsound Single Knob fuzz box, see Fig.3. These large-case glass SO-25 types were then miniaturised down to the DO-7 glass-case OA91 and AA119 devices. There is also a popular US germanium diode, the 1N60, which is still available, albeit at high cost, from companies such as Tayda. Their advantage is the low turn-on voltage of around 0.25V and their 'soft knee', the point where forward conduction begins. It gives a 'soft' distortion when used for fuzz boxes. They are also still the most sensitive device for crystal sets (although gallium-arsenide types can have a lower forward voltage). Today, these are often replaced by the more consistent schottky diodes, such as the BAT42, but to a discerning guitarist, nothing sounds quite as good

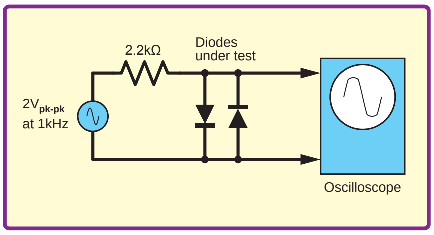


Fig.4. Clipping circuit to test different diodes

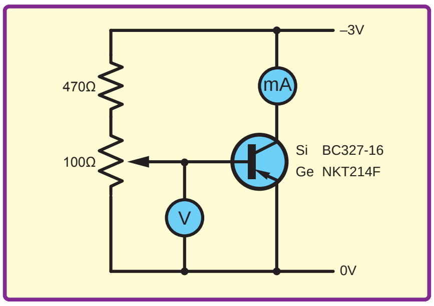


Fig.6. Transistor test circuit to compare the transconductance (base voltage vs collector current) of germanium and silicon transistors

as selected germanium devices. (I find musician's ears are finely tuned to distortion changes with level). Fig.4 shows a clipping circuit using various diodes. The resulting waveforms are shown in Fig.5.

With transistors, guitarists can also hear the differences between germanium and silicon. You can't 'see' it on a

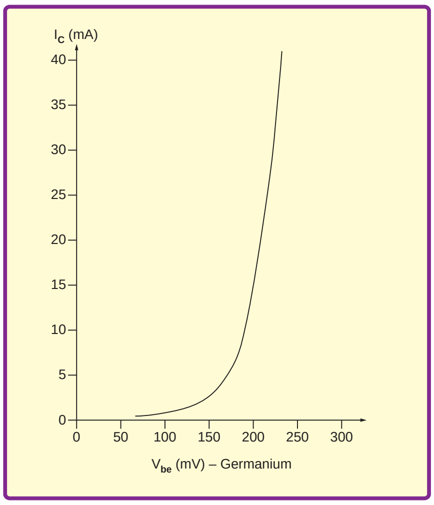


Fig.7. Germanium transconductance curve

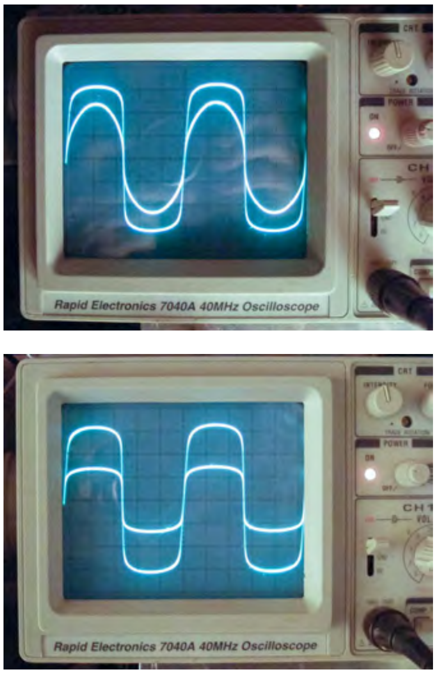


Fig.5. Clipping waveforms of various diodes. (Top) 1N4148 silicon compared to OA91 germanium, note the more rounded shape and lower amplitude of the germanium diodes. (Bottom) Comparison of silicon with BAT42 schottky diodes – the schottky diodes have lower amplitude, reflecting their lower forward voltage drop

'scope, but open-loop (with no negative feedback) they are supposedly more linear than silicon, reputedly having a less abrupt turn-on. Being a born sceptic, I distrusted the curves given in previous articles and amplifier books, so plotted my own, using the test circuit in Fig.6. This resulted in the collector current (I_c) vs base voltage (V_{be}) or transconductance curves given in Fig.7

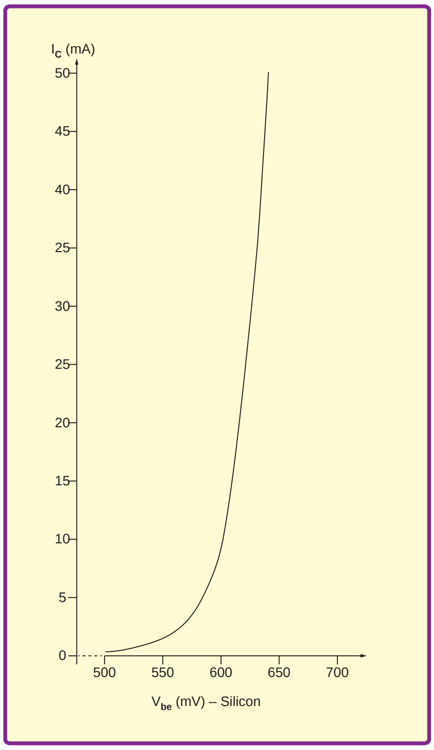


Fig.8. Silicon transconductance curve

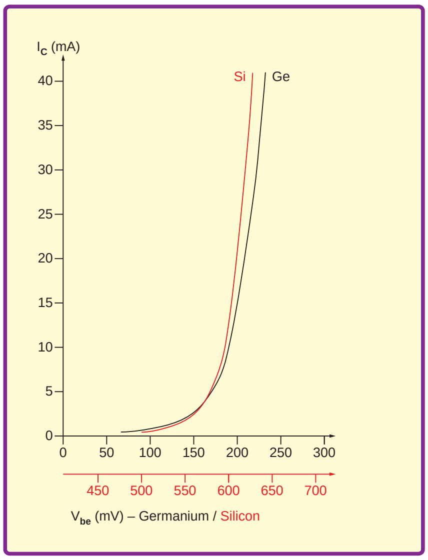


Fig.9. Comparison of silicon vs germanium transconductance curves

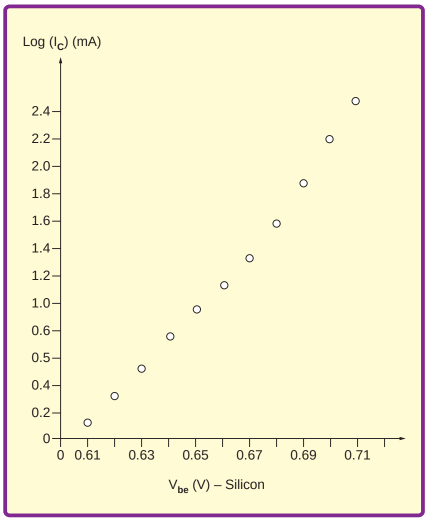


Fig.10. Logarithm of collector current vs base-emitter voltage gives a straight line with silicon. Germanium is the same but slope drifts badly with temperature.

and Fig.8. Using typical germanium and silicon audio 'driver' transistors (NKT214F and BC327), I found the germanium 'knee' to be only slightly softer. Overlaying the curves to take into account the different threshold voltages shows the difference in Fig.9. Both curves follow the usual logarithmic increase in I_c with increasing V_{be} in accordance with the physics of normal bipolar transistor action. I started to plot this, logging the current to see if I got a straight line, which I did (Fig.10) although I did feel like I was back at school! (As an aside, it was the improved stability of silicon transistors that allowed proper logarithmic signal conversion, which paved the way for Moog's analogue synthesiser.)

The Bailey amplifier

In November 1966, AR Bailey published a transformer-driven class AB Hi-Fi amplifier in *Wireless World*. It had low total harmonic distortion and it

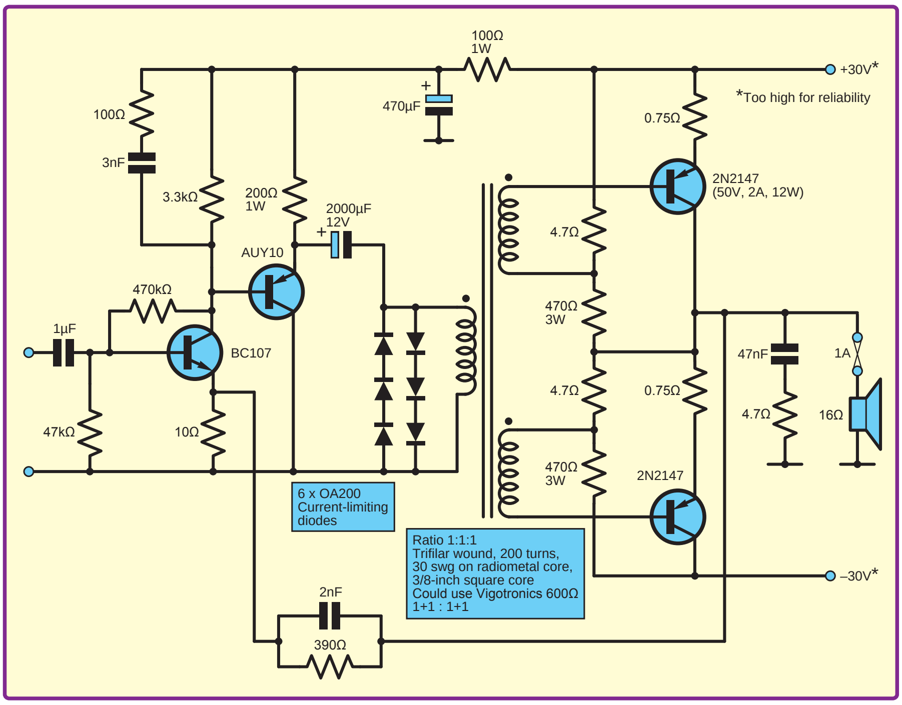


Fig.11. AR Bailey's 1966 transistor power amplifier used a driver transformer to give phase splitting and deal with leakage currents. Distortion was much worse with silicon transistors.

used germanium, not silicon transistors (see Fig.11). Then, in November 1969, John Linsley-Hood published another amplifier in *Wireless World*, and he also found lower distortion with germanium transistors in a standard common-emitter amplifier (Fig.12). (I tried but couldn't replicate this result. His circuit seemed to clip softer, rounding off square waves, but I suspect this was due to high internal feedback capacitances. Of course, the higher open-loop gain obtained with multiple silicon transistors, means silicon distortion can be made much lower when high negative feedback is applied.)

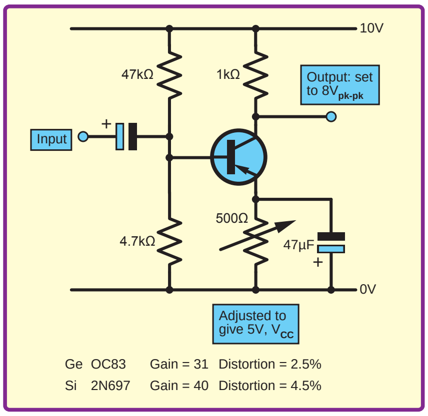


Fig.12. Common-emitter amp for comparing silicon and germanium transistors.

Germanium Hi-Fi

The first transformerless Hi-Fi amplifier was germanium-based, developed by HC Lin at RCA in 1956. It used a quasi-complementary output stage with a single low-power NPN device, the rare 2N35 – see Fig.13. The elimination of audio transformers was essential to allow high levels of negative feedback and the consequent reduction of distortion. Later, this circuit was developed by Toby and Dinsdale for a constructor's version in *Wireless World* in 1961. It was actually a rehash of a Lin-derived guided missile servo amplifier they had designed earlier, which they found also sounded rather good! The single NPN, now a 2N388A, again caused sourcing problems, with the only UK NPN device available at the time – the OC140 – tending to blow up. Later, Mullard produced the AC127Z, a selected AC127, which had sufficient V_{ce} rating.

That's all we have space for this month – more on *Ge-mania* in the next issue!

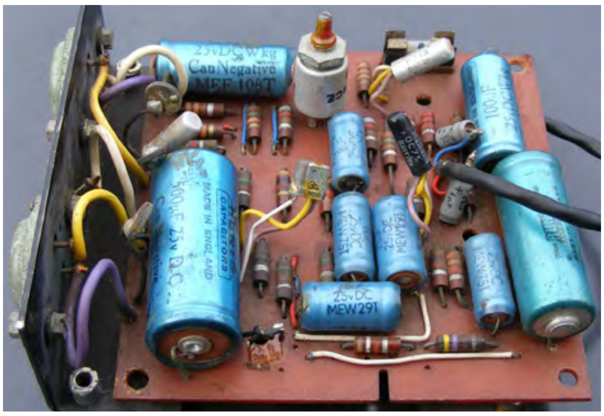


Fig.13. Power amplifier based on the Lin design from the early 1960s. The three-lead 2N35 in the silver can (dead centre) was one of the first NPN germanium transistors, allowing elimination of transformers in amplifiers.

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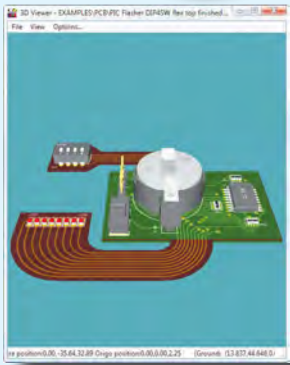

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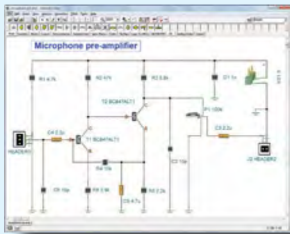

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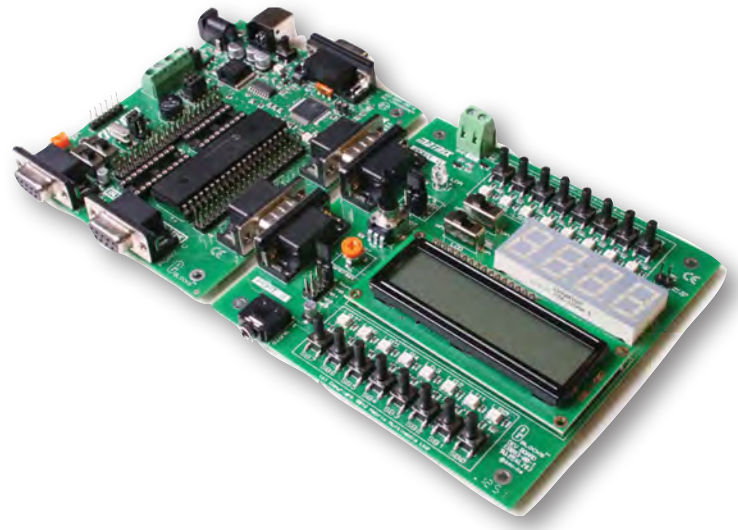

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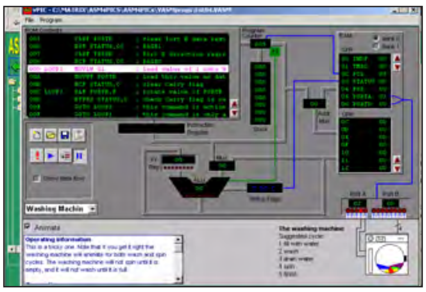

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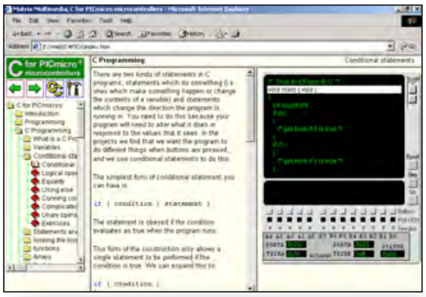

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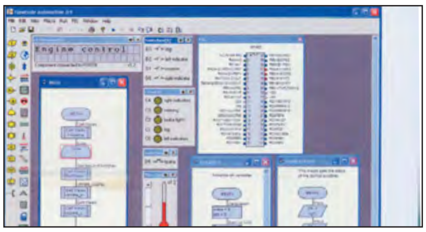

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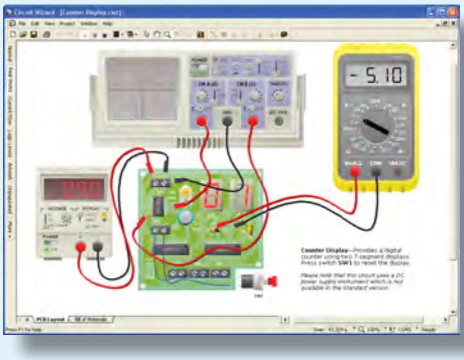

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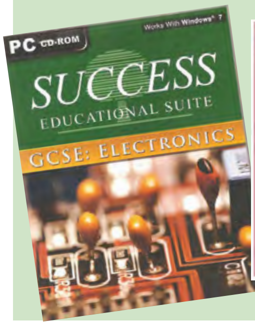

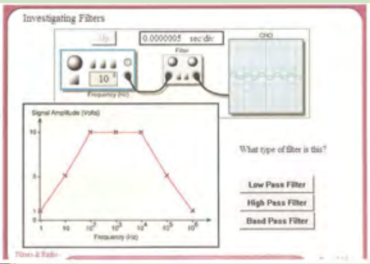

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☆ LETTER OF THE MONTH ☆

PICking up after a few decades away from electronics

Dear editor
Many years ago, I was a keen electronics enthusiast and I used to build all sorts of projects using discrete components as well as TTL and CMOS chips. (Valves too – remember those?!) After being distracted by work for several decades, I've just retired and would like to dust off my soldering iron.

To help with this, I've bought a few recent copies of *EPE* and they certainly contain some very interesting projects. Some of the most interesting, however, use PIC microcontrollers. I know nothing about these or how to load programs into them and Google hasn't been too helpful. I can find suggestions for programmers that need serial ports and software that runs under Win 98 or XP, but frankly I don't have any computers that old! I've also found introductory documents to download, but these seem to be almost a decade old.

I've searched Amazon for books on the topic, but they all appear to be priced at £20+ and to deal mainly with learning to write programs for PIC devices.

I'm totally confused! Where do I start? Surely there must be an easy way in, or no one would be interested in a 'simple' project like the ladybird in a recent issue.

Keith Wilson, by email

EPE *publisher Mike Kenward replies:*
Hi Keith, and welcome back. Things have moved on a bit in the last few years, but we are sure you will enjoy using the new devices – if you can still call them new! We do sell half a dozen books on PICs, but as you have pointed out they are all fairly expensive – see the shop on our website for full details. We also sell the PICmicro Development Boards and software – again quite expensive – but once you have bought the basics and gone through the learning curve then, of course, it is cheap to build the various projects.

I'm sure that if you post a question on our Chat Zone *there will be a number of readers that will offer advice on how you might do it for less money. Some* EPE *advertisers and Microchip itself offer a number of quite cheap programming boards, so you could also take a look at their websites.*

I hope that helps and I'm sure you will get plenty of enjoyment from learning all about microcontrollers.

EPE's PIC n' Mix *columnist Mike Hibbett replies:*
Starting out in any new venture is always daunting, especially when you are at the stage where you are not even sure of the correct questions!

I did a Google search for the phrase 'beginning PIC programming' and the first link that I received looks like a reasonable starting point:
http://blog.irwellsprings.com/getting-started-with-pic-microcontrollers

I would say follow that one, and if you have any questions, raise them on our Chat Zone *forum:*
www.chatzones.co.uk/cgi-bin/discus/discus.cgi

There are many, helpful and friendly people there. Your questions will certainly be of interest to other people, so don't be afraid to ask.

All the best, and I look forward to hearing from you on the forum.

Keith Wilson followed up his first email:

Dear editor
Thanks for your very helpful responses to my query about PIC micro controllers. Looks like I've got some reading to do if I'm to catch up on the last decade or two of developments in hobby electronics!

Actually, it should be pretty easy for me to get to grips with PIC controllers as, way back in the late 1970s, I wrote most of the application software for a project using some of the very first industrial programmable controllers. These were used to control a high-density polyethylene plant in what was then the USSR. Effectively, my colleagues and I worked in machine code – not even assembler – and we didn't have little luxuries like semiconductor RAM and ROM memory.

The machines had memory cards with 48 tiny ferrite toroids on them. We programmed them by threading enamelled wire of about 1mm diameter through and round these toroids – through if we wanted a binary 1, and round for a binary 0. The word length was 12 bits, and each card could accommodate 256 instruction words. The total capacity for each controller was 1,024 words.

Just as the project was finishing, we received some RAM cards which were a great help to program development as we could enter code from an enormous teletype machine rather than having to 'knit' it onto the memory cards – although the 'knitting' still had to be done once the code had been proved as we had no non-volatile semiconductor memory.

The only problem with those early RAM cards was that their current consumption was huge – we had to connect them to car batteries for them to retain their contents over a weekend! The mains PSUs always got hot – they were designed for 220V supplies rather than 240V – so we didn't dare leave them on when there was no one in the factory!

PCB mystery

Dear editor
Cleaning up my drawers, I found three PCBs I bought many years ago from *EPE*. One is labelled as '220a', another '221' and the third has no inscription (however, I think it is related to the previous).

What can I do with them? Is there a file explaining its design?

Christian Vauge, by email

Alan Winstanley replies:
If you search for those numbers in our Online Shop at: **www.epemag.wimborne.co.uk/acatalog** *then the project titles are displayed (~1999), assuming they are one and the same.*

220a is a Wireless Monitoring System Transmitter (February 1999)

221 is a Time & Date Generator (March 1999)

I guess the unmarked one is a Receiver PCB (219a?) for 220a.

Please note this information is unchecked and is subject to positive identification. It would be necessary to acquire reprints of the original constructional articles. We don't usually provide back issues from so long ago and unfortunately we can't offer technical support for old projects, but someone may be able to help you by checking our forum at: **www.chatzones.co.uk**.

Jacob's Ladder components

Dear editor
Thank you for the interesting article on Jacob's Ladder, *EPE*, April 2014. I would like to build this project – do Jaycar offer a kit for the high-energy ignition module on which the project is based.

Given the lack of a kit, could you possibly suggest a local or UK supplier that may stock these, and what seem to me (of somewhat older school), more specialised components such as the IGBT Q1 (ISL9V5036P3) and the 13.6V TVS.

Any leads you may have in this regard would be much appreciated.

Stephen O'Neill, by email

Matt Pulzer replies:
Unfortunately there isn't a kit for this project – I wish there were!

We did think carefully before running this project because we could see that sourcing some of the parts was a non-trivial exercise. On the other hand, we felt that it was sufficiently unusual and fun to be worth the extra effort. You can get some of the parts from Silicon Chip:
www.siliconchip.com.au/Shop/7/1410

And the PCB from Wimborne, the publisher of EPE.
The transformer is possibly the trickiest bit to obtain, but you can get it from eBay, I think the article text is clear about what to look for.

Farnell do a cheap 13.6V TVS:
http://uk.farnell.com/on-semiconductor/1-5ke16ag/diode-tvs-1-5kw-13-6v-unidir-axial/dp/2317519?Ntt=2317519

As always, Chat Zone *is the best place to go to if you need to source something tricky:* **www.chatzones.co.uk**.

Betty's still flashing!

Dear editor
'Betty's Flasher' – just a line to let you know I built this project in (published in *EPE*) September 2004. It is still flashing, although at a slower rate – I'm very impressed.

John Williams, by email

Matt Pulzer replies:
One of Thomas Scarborough's many inspired Ingenuity Unlimited *submissions – great to hear it's still running!*

Congratulations on 50 PE years

Dear editor
Thank goodness you remembered – I almost thought that your half-century landmark might have passed without anything more than a whisper among us readers. I especially remember *PE* and the early 60s and 70s articles. In fact, I have a collection that is still in my attic that ran from the first issue to the last of 1982. My favourite articles were the *PE Analogue Computer* (*PEAC*) of D Bollen (1968/9) and the *Nucleonics* series by ML Michaelis (1967/8). Also, the excellent stock market game by BH Baily (December 1968) which was published in the days when digital electronic projects were rare. To these authors who turned my textbooks into real life and practical projects, I owe my thanks. In fact, *PE* helped launch my career through university, a PhD in solid-state physics and has always been with me throughout my academic and brief industrial career up until my retirement. Sadly, I did not have the time to build many of the projects – not until the 80s, when I built one of the first DMMs from the advertised kit and later the PE Ranger CB radio transceiver, which got me back into ham radio.

I have often wondered whatever happened to those great authors whom I so admired. Unlike your sister *PW* which had occasional articles about its early pioneers – FG Rayer and FC Judd to name just two – *PE* is rather lacking in this respect, which is, after all, our history and heritage. Why not do some research and produce some articles on them and let us pay tribute to Bollen, Michaelis, Hirst *et al.* The latter's *PE Communications Receiver* (1969) in a plug-in modular construction chassis was way above most commercial sets in, specs even by today's standards.

Having said that, a general call should be made for constructors who have built or improved on those early projects and – perhaps, who knows? – gather them into a *PE* 50 Years Museum. Now that's an ambitious project. I still have many parts gathered for the *PEAC* which never took off and well, any volunteers who might want to build and/or redesign the discrete early 2N2926 Bollen *PEAC* op amps from scratch? Perhaps someone may still have a *PEAC* built lying around in the garage that can be used for solving interesting differential equations.

Tuck Choy, by email

Matt Pulzer replies:
Thank you for your tribute to PE*, the Museum idea is a fantastic one. Plus, it would be instructive and great fun to see those early projects running via YouTube.*

Project file location

Dear editor
What should I do to get PCB artwork and code files?

Christiannn van Wyk, by email

Alan Winstanley replies:
The way that our source code and PCB files evolved over the years has become messy to handle, so I recently created a new Help page which will hopefully explain the score for projects past and present. For more details, please visit: **www.epemag.com/library-help.html**

If you know the month and year of publication then you can download a .zip file from the corresponding issue's web page. The Library or Projects web links on the EPE *website will lead you there.*

Legacy source codes for the oldest projects (1996-2008) are downloadable from **www.epemag.net***, a separate website that I run myself in support of* EPE.

Please note that PCB artwork PDFs before approximately the March 2006 issue are not available for download, and from the July 2013 issue, PCB artwork for 8-digit code PCB artwork is available free to EPE *subscribers, or to non-subscribers for a modest cost. Details are available from* **enquiries@wimborne.co.uk***. If you can't find a specific project please drop me a line and I'll try to help*

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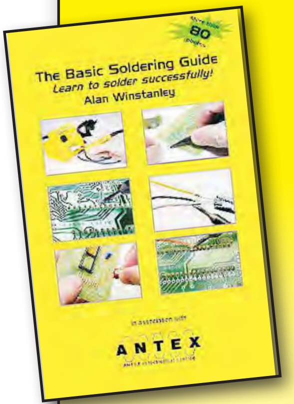

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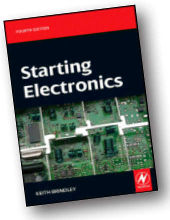

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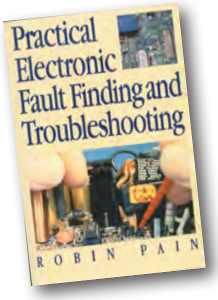

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PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. * **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

PROJECT TITLE	ORDER CODE	COST
JANUARY '14		
Champion	1109121/2	£8.88
Simple 1.5A Switching Regulator	18102121	£5.53
FEBRUARY '14		
2.5GHz 12-Digit Frequency Counter – Display PCB	04111122	£12.88
– Main PCB	04111121	£27.13
– Front Panel	04111123	£22.38
High-Energy Electronic Ignition System	05110121	£9.10
Mobile Phone LOUD Ringer!	12110121	£9.10
MARCH '14		
Extremely accurate GPS 1pps Timebase For A Frequency Counter	04103131	£8.88
Infrasound Detector – Pre CHAMP PCB	01107941	£5.54
– CHAMP PCB	01102941	£5.54
Automatic Points Controller (inc. 2 sensor PCBs)	09103132	£13.42
Automatic Points Controller – Frog Relay	09103133	£5.54
APRIL '14		
A Capacitor Discharge Unit For Twin-Coil Points Motors	09203131	£9.10
Deluxe GPS 1pp Timebase For Frequency Counters	04104131	£16.66
Jacob's Ladder	05110121	£9.10
MAY '14		
The CLASSiC-D ±35V DC-DC Converter	11104131	£16.66
JUNE '14		
Mini Audio Mixer	01106131	£22.06
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Teach-In 2014 – Part 9 Pi Camera Light	905	£13.44
JULY '14		
Verstile 10-Channel Remote Control Receiver	15106131	£16.66
IR to 433MHz UHF Transceiver	15106132	£9.10
Li'l Pulser Model Train Controller Main PCB	09107134	£16.66
– Front & Rear Panel Set	09107132 / 09107133	£17.20
AUG '14		
Active RF Detector Probe For DMMs	04107131	£8.02
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UHF To Infrared Converter	15107132	£9.64
Revised 10-Channel Remote Control Receiver	15106133	£16.66
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Lifesaver For Lithium or SLA Batteries	11108131	£5.32
Do Not Disturb Phone Timer	12104131	£9.10
OCT '14		
SiDRADIO – Main PCB	06109131	£24.75
– Front & Rear Panel Set	06109132 / 06109133	£19.35
Hi-Fi Stereo Headphone Amplifier – Part 1	01309111	£16.65

PROJECT TITLE	ORDER CODE	COST
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GPS Tracker	05112131	£13.15
DEC '14		
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– Microphone Input	01111132	
– Guitar Input	01111133	
Electronic Bellbird	08112131	£11.53
JAN '15		
"Tiny Tim" Stereo Amplifier	01309111	£16.65
– Power supply	18110131	£11.80
FEB '15		
Audio Delay For PA Systems	01110131	£13.42
Teach-In 2015 – Part 1	905	£9.33
MARCH '15		
Stereo Echo & Reverb Unit	01110131	£13.42
Super Smooth, Full-range, 10A/230V Speed Controller for Universal Motors	10102141	£11.80
APRIL '15		
A Rubidium Frequency Standard For A Song	04105141	£8.02
USB/RS-232C Interface	07103141	£7.48
Teach-In 2015 – Part 3	906	£8.75

*** See NOTE left regarding PCBs with eight digit codes ***

Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.
Boards can only be supplied on a payment with order basis.

EPE SOFTWARE

★ All software programs for *EPE* Projects marked with a star, and others previously published can be downloaded free from the Library on our website, accessible via our home page at: **www.epemag.com**

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards can also be downloaded from our website (**www.epemag.com**); **go to the 'Library' section.**

EPE PRINTED CIRCUIT BOARD SERVICE

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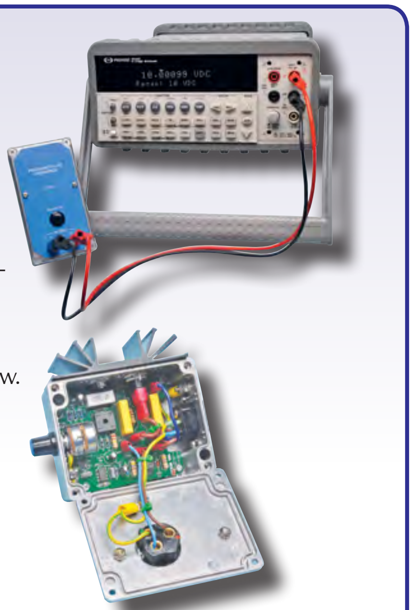


Low-cost precision 10V DC reference for checking DMMs

Ever checked the calibration of your digital multimeter? OK, we 'know' you probably haven't because there's no easy or cheap way of doing it. But now you can, with our low-cost precision 10.000V DC voltage reference, accurate to within ±5mV or ±0.05%.

Deluxe Fan Speed Controller

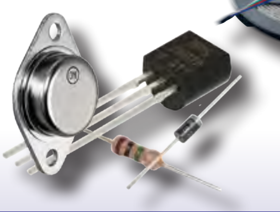
Got a ceiling fan or pedestal fan? With limited speed settings they are often too fast or two slow. This non-switched controller gives you continuous speed control and it even doubles up as a dimmer for desk and reading lamps up to 60W.

Phantasmagorical RGB LED Strip Driver

This small module drives up to six RGB (red/green/blue) flexible LED strips to produce a rainbow of colours in multiple eye-catching patterns!

Teach-In 2015 – Part 4

In May's Teach-In 2015, we will show you how we used our favourite software applications – TINA and Circuit Wizard – to design, analyse and construct the headphone amplifier. Plus, we'll cover distortion and constant current sources.



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